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ENACTING SCIENCE

BY

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This work is dedicated to my parents,
Donald C. MacDonald and Mary S. MacDonald

ABSTRACT

My study examines the development of forms of knowing that arise when students engage in open-ended explorations involving self-directed design and building involving simple materials. It is grounded in an enactivist theoretical perspective on cognition which holds that the creation of action-thought processes for engaging the world is interwoven with the meanings that are constructed for these experiences. A dynamic conception of persons-acting-in-a-setting is fundamental to an enactivist view of cognition.

How is understanding enacted in building activity? How does the shape of a problem emerge? How do students enact meaning and understanding when they experience a high degree of physical engagement in building things? What are some characteristics of an enactive learning/teaching environment?

My research settings comprise a range of individual, group and classroom engagements of varying lengths over a three and one-half year period. The first research episode involved two grade eight students in an investigation of **Paper Towels**. The second four month engagement was in a grade nine science class that culminated in the building of a **Solar House**. The third grade ten episode involved a one month project to build a **Mousetrap Powered Car**. A fourth **Invent a Machine** project was conducted in two grade eight science classes taught by the teacher who participated in the Solar House project. Two students were present in three of the four projects. I interviewed one of these students upon completion of his high school physics courses.

I found that building is a form of thinking which develops competency in managing complex practical tasks. A triadic relationship of exploration, planning and acting is present. Practical and procedural understandings emerge as students enter and re-enter self-directed problem settings. Thinking patterns depend on the kinds of materials chosen, the

ways they are used, and on how students contextualize the problem. Classroom assessment procedures gain complexity and incorporate process components as students become involved in establishing criteria for their work.

Contemporary science programs emphasize using performance criteria to evaluate student learning in investigative activity. My study seeks to expand the notion of performance by identifying and portraying essential features of student action-thought.

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Chapter 1: The Problem

Building is important for getting you thinking. (Keith, grade 8)

Introduction

Classrooms are complex environments. By complexity we refer to patterns of mutual interactions which emerge from different scales of involvement and analysis. Such complexity may be viewed as organic in its nature in that it is dynamical and evolving in its structures and processes. The pathway to describing and understanding the complexity of the classroom learning/teaching experience for its participants involves looking at the nature of the action-thought pathways created by students and teacher as they engage in curricular tasks which can be carried out and interpreted in ways allowing for individual initiative and imagination.

My research interest in enactive forms of knowing (Maturana and Varela, 1987; Varela, Thompson and Rosch, 1991) is grounded in both practical and theoretical concerns. The current cycle of curriculum revision in the sciences recognizes the multiplicity of varieties of knowledge that together form the domain we characterize as science (Martin, Kass and Brouwer, 1990; Kass, 1990). Science curricula today incorporate historical, science-technology-society, and nature of science dimensions among the aspects of knowledge to be introduced to students. While epistemological complexity has been introduced, a corresponding introduction of complexity to descriptions of learners in their varieties of ways of engaging in learning and meaning-making is just beginning to emerge in the discourses on the teaching of science (Shapiro, 1994; Roth, 1995). The learner's role is still regarded as primarily one of assimilating and re-presenting in a symbolic propositional way the facts and principles of science. The current preoccupation with assessment reinforces this orientation.

At the same time, questions surrounding the nature and function of human cognition are receiving renewed theoretical attention. Discussions of its nature or whether indeed there is such a thing as a cognizing subject are achieving a new relevance in relation to fundamental questions of biological evolution (Maturana and Varela, 1987), cognitive science (Churchland, 1984) and the construction/re-construction of the self (Searle, 1992; Bateson, 1979). Varela, Thompson and Rosch (1991) have proposed the term **enaction** to emphasize their conviction that

> "... cognition is not the representation of a pregiven world by a pregiven mind but is rather the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs." (p 9)
>
> "cognition is no longer seen as problem solving on the basis of representations; instead, cognition in its most encompassing sense consists in the enactment or bringing forth of a world by a viable history of structural coupling. (p.205)."

Varela, Thompson and Rosch (1991) are among those challenging the assumptions of Cartesian thought, namely separation of mind and body (i.e. the self and the environment), thought and action, product and process (Merleau-Ponty, 1962; Foucault, 1977; Kuhn, 1970; Polanyi, 1983). Held in common among these theorists is the position that knowledge cannot be separated from the knower (Kuhn, 1970; Polanyi, 1983), the actions of the knower (Foucault, 1977) or the knower's environment (Merleau-Ponty, 1962). Our knowledge is constructed in our dynamic encounter with the environment in which our activities are constituted (Lave, 1988). Furthermore, the notion of environment is made complex by recognizing that it has a dynamic quality of its own. Varela, Thompson and Rosch (1991, p.174) note that "organism and environment as bound together in reciprocal specification and selection."

The science learning settings of interest in my study are ones in which students engage in thinking, planning and acting processes directed towards the design and development of some type of constructed object or model. This construction is to meet a particular goal or end-in-view - it must "work" in the sense of achieving this goal and its functioning is demonstrated as a part of the project.

Research questions surrounding the nature and development of knowledge-in-action - i.e. **enaction** imply an investigative stance that recognizes the mutually specifying nature of the knower with their environment. Organism and environment are mutually constituted in an ongoing interactive process (Merleau-Ponty, 1962; Maturana and Varela, 1987). One cannot conceptualize one without the other. For example, the perception of a non-newtonian material can be thought of as an enacted experience. A non-newtonian material (e.g. mixture of cornstarch and water) is characterized by the fact that certain of its properties change depending on how the material is handled by the perceiver. If the material is deformed on a fast enough time scale then it will appear to the person handling it to have solid like properties. Conversely, the person engaging this environment will experience the material as having liquid like properties if it is deformed on a slower time scale.

Enaction and Knowledge Building

A perspective on cognition as enaction and knowledge-building based on an expanded view of its nature and development holds promise for the exploration of the learning-teaching process. For too long school learning has been confined by a view that it can be represented as facts and principles to be transmitted to the student. The job of the learner is to assimilate these and to reproduce them when required on tests. In the case of practical activity, the role of the learner is often simply to reconstruct a known result. When students are asked to be creative, the focus is typically placed on the outcome of their activities. Consequently, students do not consider the pathways of action which they create in the process of learning to be a significant part of their learning. This view is reinforced by the product or outcome orientation inherent in most school activities.

There are many ways of engaging in intelligent action (Gardner, 1993). A school classroom is a complex cognitive system at the individual, group or classroom levels in that it is continuously evolving. It can be thought of as being a dynamic environment that yields many kinds of connections and possibilities for intelligent action. Classrooms may be viewed as

> "about or directed toward something that is missing: on the one hand, there is always a next step for the system in its perceptually guided action; and on the other hand, the actions of the system are always directed toward situations that have yet to become actual (Varela, Thompson and Rosch, p. 205)."

A classroom is simultaneously a growing organism and a pattern of growth. This is similar to a plant expanding its network of root structures. Many "next steps" in the growing network can be perceived but a detailed pattern is never fully realized. Both the root structure and its environment develop together. A burst of growth in one area of soil expands the root network in that area of soil and typically reduces the amount of water in that area of soil. Similarly, an environmental change (i.e. a reduction in the amount of water in one part of the soil) will encourage root growth in a new area of soil. In other words, the growing root pattern plays a role in determining its local environment and, conversely, the local environment contributes to the determination of the pattern of growth in the root structure of the plant (i.e. they mutually determine each other).

A classroom is constituted by persons engaged in actions directed toward (1) the resources and phenomena at hand, (2) their own personal histories, and (3) other persons. Each of these may be thought of as being in a state of constant flux. A classroom community is constantly projecting itself along many potential pathways toward multiple future states but its pattern emerges only in present action. In the vocabulary of Varela, Thompson and Rosch (1991), a structure and its environment are said to **coemerge** in the sense that each depends on the shape of other to realize its own shape. Each is a pattern which continues to emerge and reemerge in tandem with the actions taken and serves to enable more actions. Given that a classroom is also a social setting this can occur on multiple levels and on multiple time scales.

Petroski (1992, pp. 127-129) describes how craftsmen through the ages have developed hundreds of new uses and purposes for the tool we call the "hammer" by using it in many different situations. In tandem with the development of its varied uses, the hammer itself has evolved into multiple forms, each one capable of performing some function all other hammers fail to accomplish - at least according to the inventor. Thus it can be said that, for the "hammer", form and function coemerge.

Petroski (1992, pp. 125-126) also describes a similar progression in the development of the American "polled ax". The ax was originally designed with a single edge. Farmers had easy access to sharpening tools to hone a dulled ax but woodsmen working far from home did not. Thus the two-edged ax emerged and woodsmen were able to travel farther from home in their work. As woodsmen encountered different trees in different parts of the country the ax continued to evolve into new shapes. Over time, as different people used the ax, each with their own personal approach and preference for wielding it, the diversity of its forms and the variety of its uses increased even further. People put their own personal stamp on the form of the ax as the form of the tool contributed to their understanding of its utility. Form and function coemerge for "persons-axing-in-setting".

It is the doing and the mutuality of the interaction that emerges among the participants in the action-setting that is of particular interest to me. My hypothesis is that, given the appropriate conditions, students build their own meanings of and actions for the

processes they use to develop knowledge during scientific activities and investigations. The action-thought processes are intricately interwoven with the kinds of meanings they construct. In other words, ***thought and action are not precursors to or outcomes of understanding, they are understanding.***

The purpose of my study is to identify features of the knowledge building processes that students spontaneously create as they develop meanings and understandings.

Thinking and understanding for students in science classrooms is a process which is highly contextualized and occurs on multiple levels within time and place. An important consideration is that settings characterized by a high degree of thought and action and an extended period of time are essential for revealing the processes formulated in constructing-enacting understanding. There are theoretical and methodological reasons for choosing settings of this kind. First, settings which require a high degree of physical engagement allow students to embody their ideas and understandings in their actions. High activity settings also open up opportunities for the researcher to participate with students as an active meaning maker who can engage both phenomena and people in the setting. Second, self-directed settings allow students to choose their own ways to develop meanings and understanding. A self-directed student is also free to choose if, when, and how the researcher can participate with them in a setting. Third, students who build physical artifacts experience the evolution of a setting which has embodied within it their physical actions. Physical artifacts provide an object of discussion, an opportunity for conversation, around which students seem to be able to describe in detail their actions and ideas both during and after a building activity.

Building is a kind of activity which can provide opportunities for collaboration between students and the researcher. Students who consider a researcher or teacher to have been an active contributor to the development of a physical artifact seem to talk easily about the physical artifact and the actions and ideas that were chosen and rejected during its construction. Settings which provide extended time provide both student and researcher with more opportunities to explore and find ways of enacting action-thought which they consider to "work" for them. Extended time provides opportunities for the researcher to engage students in conversations about their thinking during a project as opposed to after it has been completed. Therefore I will examine the nature and development of enactive forms of knowing/understanding in science knowledge-building settings in which students engage in open-ended activities involving self-directed design and development of a model and structure. To reiterate, my focus is on the processes students use to generate the outcomes of their activities, not only on the products they generate. There are two general purposes: (1) to explore enactivism as an interpretive framework for research on student understanding in action, and (2) to portray features of knowledge building processes and environments as revealed by an enactivist stance.

Enaction and Self-direction

Knowing is a form of practical activity. By practical I mean action-thought directed toward something which is in the process of being created. For example, the construction of a device to keep an ice cube from melting involves knowledge of materials and heat transfer put into practical action. The practical actions generated during such an activity are both a process and an outcome to a process.

There exist various types of science classroom activity and each calls for exploration of its properties in knowledge building on its own terms. At the level of embodied process (Johnson, 1989) context and problem create each other (Lave, 1988; Chaiklin and Lave, 1993). In science classrooms, I have noticed that students often transform a problem setting into something which they consider more workable and meaningful than the one initially set by a teacher. For example, I recently taught a group of grade nine students a unit on electricity. One activity I asked the students to do involved exploring what happens to the brightness of small light bulbs arranged in a series circuit when the number of bulbs included in the circuit is changed. Students also used a hobby motor in their circuit as a device to reduce the current in the circuit and prevent bulbs from burning out. Some students noticed that they could change the brightness of their bulbs when they squeezed the spinning axle of their motor, reducing its rate of spin. Squeezing the motor axle was not something I had considered as a possibility when I selected this activity. Exploring this dimension of the problem context changed the setting for these students and new possibilities for action-thought began to unfold. Suddenly the problem focus was shifted from understanding light bulbs to understanding hobby motors and these students took the initiative to dismantle (after asking for permission) and investigate the inner workings of the motors.

The learner's active participation in transforming a context has a powerful impact on the shape of the problem and the kinds of questions which emerge. Active participation means that the learner is implicated in the experience of transforming the context. In other words, the learner must "feel" her role as an agent of change, through her actions and thoughts (i.e. action-thoughts) in transforming her world. Transformative action may be motivated by a student's intrinsic desire to act in a way (s)he considers successful. When a student does not initially "see" or "feel" a way to act successfully within a problem setting (s)he spontaneously searches for new ways to accomplish this goal. The affordances of action which are available to a student in a setting play a role in determining if and how (s)he transforms the person-setting unit into a viable entity.

For instance, it has traditionally been the case in practical science activity to provide students with what a teacher decides is "just enough" materials and equipment in order to accomplish a task. Most students quickly become aware of this and engage in their practical work with such a constraint in mind. When a student does not consider herself to be implicated in shaping the environment, what viable actions and understandings can be expected to emerge? This seems to be an open question.

Piaget in conversation with Bringuier (1980) describes the actions of an organism within their world as emerging from two goals:

> The two objectives of behavior are, first, the extension of the environment, having an environment larger than the present one, ..., and second, the increase, the growth of the organism's powers over the environment. (pp. 116-117).

The person acting is not only an agent of change within their environment but is also an object of transformative action. When both the "person-acting-in-a-setting" and the "setting-in-which-the-person-acts" are free to change the capacity of a system to become viable increases.

Self-direction is not only a "way of acting" in a world but is also a "world" within which a person acts. Setting or environment is not a backdrop but is itself a dynamic and changing set of influences. The environment itself becomes an "agent of change" which acts upon the organism. A context expands into one with more dimensions of possibility, more qualities to be noticed and acted upon, when a student considers it to have properties of self-direction. The way we perceive the world can have a dramatic impact upon how we act to have a world.

What is the nature of the understandings embodied in the actions and thoughts which emerge from a person's dynamic relationship with their world? Let us refer to them as action-thoughts for now. Johnson (1987) claims that they are the foundation of language meaning concepts. Our bodies move, engage and re-engage the world in complex ways. Action-thought can be a process quite close to what is traditionally referred to as thought (i.e. an idea that plays itself out in the mind). Action-thought can also be distributed away from that region we commonly refer to as the mind (located somewhere in the head - usually!). Action-thought can be extended out into the body: into the arms, the legs, the fingers, and into the complex ways the body makes contact with that which is not the body (sometimes called the environment). Even the tools we use can become extensions of our own body, if we allow them to be by enacting them as a part of our understanding. Action-thought can be distributed into even more complex arrangements when more than one person is involved. Piaget (1963, 1972) considers the childs' engagement in recursive action to be the way concepts and meaning are created. Scientists work in a similar way (Polanyi, 1983).

Affordances as openings to viable action

Van Aufshnaiter and Schwedes (1989) and Roth (1995) describe action settings in which students physically participate with tools and materials as being "open". An open learning system can be thought of as one containing a large and variable number of potential pathways for action-thought. Physical movement affords the body and environment multiple degrees of freedom which can actualize the cognitive system. By this I mean that the coordination of an environment and a person acting in that environment allows certain kinds of physical motion that generate new ideas in action (i.e., a new person-acting) and a new environment. For instance, the young child who through playing on a swing may discover that she can spin by "wrapping up" the chains of the swing in a circular fashion and letting go. In doing this she may also discover that she can control the rate of spin by extending and contracting her arms. After such an experience the child has developed a new understanding of herself, her way of engaging the swing, and the nature of the swing. Person and environment have developed together.

Tools and materials likewise are **affordances** of the person-environment combination which can become a part of the individual in a process Polanyi (1958) refers to as "in-dwelling". An open learning system is similar to a network of interdependent and generative affordances involving both the learner and the environment. The **viability** of a learning system is dependent on three things: (1) the number of affordances which are actualized, (2) the complexity of the coupling between affordances in the network, and (3) the capacity of the system to generate new affordances and reorganize existing ones. I will use the term learning system to mean a combination of organism and environment co-emerging in mutual specification. The number of potential pathways for action-thought of a system are not predetermined. They increase and decrease in number as the person and setting coemerge together in a process of mutual specification.

Why is Building Important?

An important component of my research approach is to identify building activity (e.g. using materials and tools to make something) as a specific type of science learning activity. Building is an inventive process that is essentially self-directed when the articulation of the problem, decisions, and actions are, within limits, initiated and controlled by the students within a relatively extended and flexible time frame. In other words, an environment for action-thought can emerge where the role and perspective of the teacher and the researcher in contributing to the unfolding nature and directions of student activity is changed. Rather than acting as an observer/interpreter of action, a teacher or researcher interacts and co-participates with students as a person interested in contributing to the maintenance of action-thought by offering assistance, commentary, and/or suggestions when invited to do so. This allows a teacher or researcher to situate himself as an occasioned listener who is equally ready to act toward a student and their unfolding setting as he is to wait for the student or setting to act toward him. Such a perspective may be more effective in allowing dimensions of student ideas and thinking to emerge because they are generated as the student and researcher act together within a dynamic setting to accomplish a goal that is mutually specified.

Self-directed building is a kind of affordance to action. It can be thought of as either a setting for action or a way for acting which can open up possibilities for exploration by a student or by a student and researcher acting together. A person engaged in building with materials (e.g. constructing a mousetrap powered car to explore energy and motion) operates in a setting where the number of affordances to action is likely to increase as the building goes forward. As the number of affordances to action grows larger, the occasions for a researcher to enter a student's unfolding setting and contribute in a way that is considered to be meaningful by the student is also increased. For instance, engagements with simple materials (i.e. scraps of wood, wheels, axles, tape, glue, string, nails, mousetrap) generally leads to a process of invention and testing. Such processes often require an extra set of hands and a researcher can find and take advantage of these opportunities when they arise.

Students seem to naturally talk about what they can do next, what they will do next, and what they would like to do next when they are engaged in building activity. However, building is also a convergent experience in the sense that limitations are encountered as action-thoughts take physical shape. An understanding of what kinds of action-thought are not possible in a given environment emerges from the experiences of building. It may be the case that this understanding of the possibilities and limitations surrounding a building activity can not be prescribed by/for a student. They must be experienced and understood in action. How this might occur is something I intend to explore in my study.

Students intuitively distinguish between activities that allow for self expression from tasks where answers are specified and outcomes are known. Open entry into activity as described by Simmt (1995) is a process which may depend on the nature of the activity and the nature of the way persons are engaged in the activity. For instance, will a student choose to enter an activity in which they have some control over factors such as time, materials, and workspace (i.e. open-ended activity) in the same way as they will an activity in which these factors are pre-specified and prepared? The way a student chooses to re-enter a process of action-thought may be more complex than it appears to an outside observer. For instance, can we say that a student considers herself to be engaging phenomena in the same way when they re-engage an activity setting? How can we know if a student is even perceiving the same phenomenon as before? The open-ended quality of building activity may introduce additional cognitive complexity in the sense that it generally requires participants to repeatedly enter and re-enter processes of action-thought. How does entry and re-entry in open-ended task environments contribute to the kinds of action-thought which can emerge during practical activity? Does the entry/re-entry into an activity or the emergence from practical activity take on different forms and meanings when it is considered from different perspectives (i.e., active participant versus observer)? I will explore issues surrounding these questions in my dissertation.

The Research Questions

The aim of my study, as stated earlier, is to identify, portray, and interpret features of the knowledge building processes that are important for students in developing understanding of the problem in which they are engaged. Knowledge building processes are enacted by students on many overlapping and interacting social-cognitive levels within a science classroom in which freedom of action is encouraged. My research questions are constructed in a way which allows me to address issues concerning the nature of knowledge building processes from various perspectives.

How do students enact meaning and understanding in a high-activity, hands-on science classroom where they are given the freedom to accomplish tasks in a self-directed fashion over an extended period of time? How can I, as a teacher or researcher, participate in such a classroom environment in a way which allows me to address how students make actual that which they consider possible? The four questions around which I will construct the report of my research findings are as follows:

1. How is understanding enacted in building activity?

2. How does the shape of a problem emerge in building activity?

3. How do students enact meaning and understanding when they experience a high degree of physical engagement in building things?

4. What are some characteristics of an enactive learning/teaching environment?

Each of these questions is explored in a chapter of my thesis report.

The need for the study and how it might inform practice in science education

The position that students develop and use their own personal approaches to construct knowledge is well established in the literature. Piaget (1963, 1972) was one of the first to incorporate this position into a research approach whose goal was to describe the nature of cognitive development. He engaged children in relatively short (several minutes) action tasks which were designed to externalize their ideas about concepts and constructed portrayals of their understandings.

The large body of constructivist research has acknowledged the importance of viewing the student as an individual and social cognizing agent. This body of research , for the large part, has focused on identifying and describing the cognitive structures (i.e., conceptions) which various people are presumed to hold. Constructivist research in cognition, although it views knowledge building as a process, has tended to focus on the outcomes of knowledge building as describing and interpreting conceptions. As Solomon (1994) points out, while constructivist research has contributed a great deal to our understanding about what people know, the problem of how they come to know it has not been fully addressed.

It has been recognized for some time that practical work is an important component of a science curriculum (Alberta Education, 1994; Project 2061, 1991). However, there is no clear understanding about how students use practical work to develop meaning and understanding. In fact, there does not even seem to be agreement on what "practical work" means. Woolnough (1991) describes practical work as a holistic process. However, as it is applied in curricula, practical work often focuses on using pre-selected materials to reconstruct a pre-defined path in order to reproduce a known result. While there is growing dissatisfaction (Woolnough, 1991; Roth, 1995; Driver, 1981; Driver et al., 1994) with this kind of context for practical work it continues to be used in many science classrooms. My experience is that this kind of practical work tends to be considered by students to be a kind of target practice. Students tend to disengage from the process and focus only on the achieved closeness of their solution to a known result or target. The process and the outcome of the process seems to have little or no sustained meaning for them and almost no generative power in terms of subsequent action-thought.

Science curricula have attempted to expand the notion of practical work to include more open-ended activities. Some curricula (Alberta Education, 1994) encourage students and teachers to explore a variety of novel materials in self-directed building and invention activities. However, little is known about the variety of processes for knowledge building that students develop when they participate in practical work or the meanings that students and teachers attach to those process. A better understanding of what knowledge building processes are used, how they are used and why they are used by students in open inquiry settings is needed if teachers are to find ways to effectively participate in these settings. My study seeks to contribute interpretive portrayals of action-thought as it emerges and develops in self-directed practical science classroom settings which can be read and re-interpreted by teachers, curriculum developers, and students who engage in and interpret the significance of practical work in learning contexts.

The importance of practical work in current curricula is highlighted by a growing interest in finding new ways in which it might be assessed. For instance, performance assessment activities are currently being developed and field tested in Alberta and other provinces in Canada. My concern with some of the current approaches to performance assessment is that they often tend to assume that the outcome of performance is a good indicator of the quality of performance itself. My own experiences in open inquiry and in participating with students in similar settings has indicated to me that such an assumption is not valid. Kass et al. (1994) have found that the interpretation of performance takes on more complexity when it is considered from a perspective which allows it to be viewed as a holistic process as opposed to a product. If approaches to performance assessment are to satisfactorily recognize that there are many ways to engage in intelligent action (Gardner, 1993) then we need to know more about the nature of processes for viable action. This goal may be more difficult to accomplish, but it is clearly needed given the current emphasis on assessing performance, and its imminent widespread implementation in Alberta and other provinces.

Brown (1992) has called for an increased understanding of how teachers can participate with students in classroom settings. Open inquiry classroom settings offer us a challenge to find ways for teachers-researchers to participate which are meaningful to both students and teachers. My participation as a researcher in these settings and the interpretation and portrayals of student knowledge building processes has the potential to inform this participation in science classrooms. A research perspective which focuses on student action has the potential to inform teacher action.

Science, Technology and Society (STS) perspectives have influenced much of the most recent curricula introduced in science education. A wide variety of perspectives can be situated under the STS umbrella and each proposes different emphases for STS science education. Such perspectives may emphasize logical reasoning (Aikenhead, 1991), history and philosophy of science (Hodson, 1985, 1988; Matthews, 1991), ethics, and socio-environmental issues. Such approaches are considered important to the development of responsible and scientifically aware members of society who can make informed decisions in a constantly changing world. However, I am concerned that the "end-in-view" may be closing off important pathways for arriving at this destination. For example, some teachers have told me that they will not allow certain materials or certain building activities in their classrooms because they are wasteful and not "ecologically friendly". So, for instance, the student who decides to explore the efficacy of using motor oil as a heat sink in building a solar collector or the student who decides that styrofoam is a good building material for a model car might find that these pathways of action-thought are closed to them. This position is justified by appealing to just one interpretation of an STS perspective for science teaching and learning which promotes environmentally responsible action.

I am certainly not arguing in favor of irresponsible use of materials. The student using motor oil and the student using styrofoam must be made aware that she/he is responsible for the safe disposal or recycling of these materials in the best available fashion. However, they should not be discouraged from using these materials to build and put their ideas into action. What meanings do students enact for the ways in which they engage the world when pathways of action-thought are restricted? My concern is that the experience of having action-thought processes blocked before they can be enacted may encourage the construction of processes for disengaging the world. Enaction might become inaction when ways to make physical contact with a world are lost or not considered to be important.

Meaningful engagement with a personally constructed world embodies a playfulness of action as well as a caring attitude for its development. A person who is not fully engaged in their world will not care about it (or for it) as much as the person who is. Responsibility is itself an action, not just a perspective on action. The pathways of action we discourage may be just as important as the pathways we encourage in our science classrooms. When we choose for a student how she/he should engage their world we may close down more than we open up. Responsible members of society know how to take action in worlds of possibility and reshape them into worlds of actuality (Bruner, 1986). A better understanding of how these processes can occur in the world of a science classroom is needed and worth striving for. This study is intended to contribute to the development of a more complex understanding of how students enact meaning and understanding through personal action in high-activity science classrooms.

Personal Ground

My experiences as a student researcher have influenced my thinking on how action-thought processes may contribute to the development of understanding. One story from an early experience in self-directed open inquiry serves to illustrate what I mean.

Learning FORTRAN

At the end of my first year of university I accepted an invitation to work with a scientist as a summer research student. I was very excited about the opportunity. I was going to be near the center of an actual research project, I was going to learn how to do things, and I was going to get paid to do it. It beat the hell out of digging up water pipe for the town of Pincher Creek, but that's another story.

I met with Ernst, the scientist who would supervise and assign me tasks. He described how our work would be a part of a larger theoretical project to understand a special class of phenomena known as phase transitions. A phase transition, he explained, was simply the occurrence of a very large change in one thing as a consequence of a very small change in another. For instance, many materials have a specific temperature where they suddenly change from one state of matter into another (i.e. solid to liquid). In such cases, a small change in temperature brings about a large change in a property of the material.

One component of the research had already been done. The outcome of that component was a set of mathematical representations for materials whose atoms were known to be arranged in a particular three-dimensional geometric distribution (i.e. body centered cubic structure). These mathematical representations took the form of a set of power series. Power series were simply ordered sequences of numbers. Taken by themselves they did not tell you much but if they could be transformed into a set of mathematical functions then a pattern of behavior might be noticeable which could be used to predict how other materials would behave.

My job was to help in the process of transforming the power series into mathematical functions. Of course this was not a simple process. Several mathematical functions could emerge as reasonable candidates for a given power series. Ernst thought it might be helpful if we explored what would happen by "working the problem backwards" (i.e. start with a known mathematical function and use it to generate a power series which could be compared with the one we were interested in). This idea was the inspiration for my first task. Ernst wanted me to write a computer program which would allow us to select from a wide range of possible functions. Ernst thought it would be a good way for me to get started. However, he did not realize that I had never used a computer before. I didn't even know how to "sign on", let alone program one. This wasn't all that unusual at that time. Computers only came in the mainframe variety at that time and were still a novel item on campus. Ernst scribbled down some sample functions on a piece of paper before announcing quickly that he was going to be away for a couple of days. "Work on your own, see what you come up with" he said as he disappeared out the door. I was so busy thinking about the problem that I missed the opportunity to tell Ernst about the extent of my experience with computers (or lack thereof).

My naiveté with computer programming emerged pretty quickly as I began my self-directed task. I had no idea about how a mathematical function could be represented in a computer program but I was pretty sure it must be possible. I dove into a book describing the intricacies of FORTRAN and decided that commands such as "Read" and "Write" were a good place good place to begin. "I'll get the computer to 'read' the function I want it to use and then 'write' it back to me as confirmation" I thought to myself. I tried doing this. All I seemed to get was an endless series of rather cryptic error messages. Why can't I just get the computer to read the whole thing I wondered as I tried typing "F(x) = (3x + 20)/(x-5)". Nothing seemed to work. I had no idea that in order to represent a function in a computer program it had to be broken down into component symbolic parts. For me, mathematical functions were holistic entities.

The nature of my confusion became apparent to Ernst and myself when he returned. He looked at my flowchart and listened as I described it for him. It was a hodgepodge of FORTRAN statements with a sprinkling of mathematical functions. Ernst thought about my flowchart for a while and thought about how I expected to be able to communicate with the machine. "He must be wondering how I ever got this job in the first place" I thought to myself. Ernst smiled and said "we should talk about operating systems soon". He said that he had often thought about how people could interact more easily with computers and that my ideas showed imagination and potential.

Ernst suggested some changes for my computer program. He wrote down a series of steps that could work. "Computers do not make functions work the same way that we do. We do it elegantly, we only need one line to understand, but computers need several steps and everything must be defined explicitly." I understood immediately. The series of FORTRAN statements Ernst wrote down took on a meaningful shape for me. I got a reasonably good program working almost immediately and it was not long before I was writing all sorts of computer programs on my own. New worlds for putting ideas into action were opening up for me and new ones were emerging. Ernst and I had many interesting conversations about computer operating environments.

Self-directed experiences of this sort have made an important contribution to the way I think and act. Creating my own ideas and putting them into action, even when they didn't work as intended, helped me to generate and play with new ideas. It also became easier to visualize ideas in motion. I began to "dream" about multiple solution paths whenever I encountered problems in mathematics, physics or computer programming. Envisioning action is itself a kind of action which can generate new worlds of action-thought. It can also make going to sleep at night take on a whole new meaning!

Learning through doing and reflecting on the doing became an empowering and exciting approach for me which has shaped more of who I am than I will ever be able to tell. I have blown up the odd power supply, crashed even more computers (big and small), and constructed lots of incorrect solutions to problems by trying out my ideas. But these experiences have enabled me develop a degree of confident playfulness and commitment for engaging with a setting that helps me better understand its shape on many different levels. I usually get as much pleasure in *wondering about possibilities* as I do in *knowing about actualities* in the worlds I enact. I want to learn more about the multiple ways other people engage in action-thought in order to bring about a personal world where knowledge building and understanding can develop.

The Research Setting

My research focus lies with a particular type of science learning activity, namely extended investigation of a problem setting that is broadly characterized as involving the construction or building of something (e.g. an apparatus or a model). The invention/building process is essentially self-directed by the students. Contributions to the nature and directions of such an emergent process is largely controlled by the students involved. The investigative sequences of particular interest in my research involve students in responding to a "variable entry" challenge by creating a personalized action-setting and constructing a physical building within that setting. By this I mean that what constitutes the problem as well as how/when it is approached is established and maintained primarily by the student in collaboration with the teacher and/or researcher. Such a setting provides a potentially action-rich learning/teaching environment which I term an ***enactive science classroom.***

My approach is qualitative and involves interacting components. During the time the projects were carried out, my supervisor and I were present every class period. We videotaped and audio-taped classroom events and groups of students engaged in investigative tasks and talked with them as they worked. I interviewed student groups when they finished their projects. My questions focused on their interpretations of their actions. I also analyzed their written work which forms one of the main sources of data in this thesis. Interviews and meetings were also held with the teacher.

A holistic approach to the portrayal of science investigative activity recognizes that knowledge and understanding have both personal and social dimensions and involve multiple meanings. My data portrayal is based on an interpretive technique which allows presentation of an investigative episode in a way which integrates four components: student actions, student verbal discourse, student meanings associated with the actions and verbal discourse, and my interpretation of both student actions and discourse. Instances are presented in the form of vignettes, extended analysis, and reflections on personal enaction. My orientation is proscriptive in nature (see p. 35). I am particularly interested in describing a diversity of conceptions of persons-acting in the various settings that present themselves. The rationale for this approach is presented in Chapter 4.

Eco (1994) uses the metaphor of "a walk in the woods" for writing or reading a story. One can experience the woods in numerous ways depending upon one's action-thoughts in a setting (e.g. to be traversed quickly, to linger, and the like). Similarly, in classroom research settings, the researcher can choose a variety of ways of participating in the unfolding dynamic. The way which is chosen influences what is salient to the portrayal (i.e. the meanings which are created for both author and reader). I recognize that as the author I create a personal account grounded in my larger research objective, namely how students think and develop understanding. My participation in the student project activities ***under the direction of the student*** is central to coming to understand what the experiences meant to the student.

My approach involves a second-order component in that the focus of my research interest (the ways students develop scientific understanding and the meanings these hold for them) is embedded within the locus of student attention (accomplishing an extended investigative task). This approach has been influenced by Marton's account of phenomenography (Marton, 1981). In phenomenography conceptions reside in the interactions people have with the world around them. Its aim is to find, describe, and systematize "the different ways in which people experience, interpret, understand, apprehend, perceive or conceptualize various aspects of reality". If the phenomena of the world are distinguished (i.e. heat, light, matter, force) then each phenomenon can be said to be characterized by an "outcome space" which describes the limited number of qualitatively different ways in which people can conceptualize the phenomenon. Phenomenographers make a distinction between first-order and second-order perspectives. A first-order perspective attempts to describe a person's conception of a phenomenon. In a second-order perspective focus is shifted from the person's conception of the phenomenon to the ***way*** in which the person thinks about it.

The implication of an enactivist perspective to research methodology is that these second-order portrayals are an important element in describing the evolution of dynamic understanding. This calls for multiple kinds of engagements by the researcher as part of the setting, and for portrayals that reflect this multiplicity of engagement. I am open to the emergence of a diversity of conceptions enacted by persons in the various settings that present themselves.

A Unit of Analysis: Students-researcher/teacher-acting-together-in-setting

As noted above, my approach is qualitative and involves several interacting components. I consider an approach incorporating multiple perspectives to be useful. For instance, if one is interested in studying something, then it is productive to view it from perspectives which are larger and smaller than the perspective ordinarily taken. This strategy is well known in science and is considered by Polanyi (1983) to be the essence of how conceptual understanding is developed. How one visits and revisits a setting can yield portrayals that focus on very different facets of the setting or situation (Eco, 1994). As noted by (Maturana and Varela, 1987, p. 26) ***"Everything said, is said by someone."*** The unit of analysis I will use is "persons-acting-in-setting" (Lave, 1988). "Persons" refers to both the students and researcher acting together in the setting. Instances will be presented in the form of vignettes, extended analysis, portrayal and reflections on personal enaction.

Chapter 2: Theoretical Rationale

> *We propose as a name the term **enactive** to emphasize the growing conviction that cognition is not the representation of a pregiven world by a pregiven mind but is rather the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs. (Varela, Thompson & Rosch, 1991, p. 9)*

> *Meaning is not created through individual intentions; it is mutually constituted in relations between activity systems and persons acting and has a relational character. (Chaiklin & Lave, 1993, p. 18)*

My research is grounded in the current orientation toward cognition loosely known as enactivism. While similar in their fundamental arguments, there appear to be two somewhat distinct groups of writers/researchers working in this area. One group of theorists (Varela, Thompson, and Rosch, 1991; Johnson, 1987, 1989; Merleau-Ponty, 1962) approach the questions of cognition from a philosophical and biological stance. The other group (Lave, 1988; Chaiklin and Lave, 1993; Salomon, 1993) ground their approach in empirical studies of what they term "situated cognition, legitimate peripheral participation, and distributed cognition". While some of the distinctions may be regarded as matters of language, there appear to be present some differences in theoretical presentation as well. I will explore some of these differences later in this section.

In this section I will lay out some ideas surrounding the following key terms in enactivism: embodiment, enaction, coemergence, structural coupling, laying down a path and adequate conduct (viability). While this listing by no means exhausts the complexities of this developing list of ideas about human cognition and meaning making, it includes the key elements that will inform both the theoretical orientation and methodological approach in my dissertation. I will also describe a fundamental reconceptualization of the relationship between person and context that is provoked by Merleau-Ponty's (1962) writings on the phenomenology of perception. Both neurophysiological and psychological work support his conjectures.

Enactivism is a complex and evolving orientation toward the study of cognition. I will argue that the ideas of enactivism may offer a way out of the present stagnation that many writers (Driver et al., 1994; Cobb, 1994; Solomon, 1994) claim afflicts the area of constructivism. While some may view enactivism as an extension of constructivist approaches to cognition I will explore some of its differences and describe areas in which enactivist notions seem to address limitations of constructivist theory and research. I will conclude this chapter with some speculation surrounding five questions:

1. What is the nature of knowing?
2. How does knowing and understanding come about?
3. Where does meaning reside for an individual, for a group, for a society?
4. How is understanding enacted?
5. What can enactivism contribute to our understanding of knowing/meaning making?

Embodiment

Johnson (1987) addresses the age-old question of how we can know and communicate our knowing to each other with a provocative linguistic hypothesis. Johnson argues that the fundamental meanings of our language reside in our bodily experiences of our being in the world. These meanings can be held in physical experience (e.g. force, energy, work as defined in the physical sciences), in social/psychological experience (hard work, high energy, forceful argument) or in the metaphoric projections of experience (e.g. life is a journey, time is an arrow, stars are constellations, curriculum is curare - running a path) (Bateson, 1979; Lakoff, 1987; Lakoff and Johnson, 1980). The three domains inform each other in the meanings we attribute to our use of language and our experiences of being in the world.

Understanding involves more than the imposition of static filters (e.g. propositions, schemata, templates, plans) to our perceptions. In Johnson's words, "understanding is an evolving process or activity in which image schemata (as organizing structures) partially order and form our experience and are modified by their embodiment in concrete experiences. (p. 30)"

The notion of image schemata is central to Johnson's description of linguistic understanding processes. Johnson (1987) claims that comprehension of meaning and connection of experiences emerges out of our having patterns and order to our actions, perceptions, and conceptions. An image schemata is "a recurrent pattern, shape, and regularity in, or of, these ongoing ordering activities (Johnson, 1987, p. 29)". Johnson's claim is essentially a restatement of Piaget's notion of schemata (Piaget, 1963). However, he extends this notion into the realm of linguistic meaning making and reasoning.

For example, the term "force" can be thought of as an image schemata which serves to organize our experiences and semantic structures. We experience force in multiple ways simultaneously. Force is experienced through physical interaction and follows a sequence of causality. It involves a sense of directionality and has a path of motion. Force is perceived as having a source and having variable degrees of intensity. Taken together these perceptual features form a holistic dynamic structure of understanding which evolves as we continue to have more physical experiences in the world. The preceding characterization of force as a repeatable experiential structure which serves to give shape to new experience is what Johnson refers to this as an experiential gestalt. In Johnson's (1987) words, a gestalt structure is "an organized, unified whole within our experience and understanding that manifests a repeatable pattern or structure (p. 44)".

Experiential gestalts are meaning making structures, not structured backgrounds for meaning making actions. It therefore follows that reasoning is something people **do** with propositions (or symbolic representations), not some abstract relation among them. Reasoning is an embodied process, not something that happens "out there". Both orientations toward enactivism (i.e., Varela, Thompson, and Rosch, 1991; Lave, 1988) share this view.

Johnson (1987, p.126) identifies twenty-seven different pervasive image schemata which he considers to be important in constraining our reasoning and understanding. Among these are **balance**, **path**, **link** and **cycle**.

Johnson holds that **balance** can be understood both as an experience and as a concept. Our multiple conceptual understandings of balance co-emerge with our bodily experiences of balance in our environment. The different senses of "balance" are connected by metaphorical extensions of balance schemata. We need to begin with the pre-conceptual gestalt structures which are embedded within our network of meanings if we are to begin to understand the term balance in a conceptual way. In other words in order to conceptualize our understanding of "balance" then we need to consider the acts of balancing in which we engage our bodies.

The meaning of balance is brought forth by acts of balancing. Acts of balancing give us experiences of balancing which are naturally organized into image-schemata (these involve our bodies and are therefore not completely abstract). The preconceptions make subsequent balancing experiences coherent and salient. In other words, the structural patterns of balance which have been brought forth by our personal histories of our being in the environment are integrated into our bodies and serve to further organize and connect our subsequent experiences with meanings.

The notion of balance in school science can take many forms, the implied meanings of which for students emerges from their "bodily" experiences. For instance, students learn about balance as:

1. a state of dynamic equilibrium when they learn about diffusion across membranes,
2. a mathematical state when chemical equations are in balance,
3. a static situation where the net force acting on an object is zero when the forces acting on it balance.
4. a tool for measuring and weighing.

Johnson argues that our intrinsic understanding of a **path** schemata involves three fundamental aspects from our experience. When we think about paths we include the notion of a starting point, an end point and a contiguous set of points linking the start to the finish. The path schemata is simply a route for getting from one place to another. However, because the path schemata arises from experience we typically incorporate many other components into our path schemata. for instance, we usually perceive a passage of time and have a purpose for moving from one place to another. Thus purpose and time can be intrinsic parts of a path schema. When Varela, Thompson and Rosch (1991) describe our meaning making process as "laying down a path in walking" they are asking us to invoke a complex set of embodied ideas in making sense of what they mean.

When students learn scientific concepts they are often asked to consider multiple image schemata simultaneously. For instance, in considering vector arithmetic students may consider notions of path, **link**, balance, part-whole and **cycle**. Consider a set of four vectors linked head to tail which form a closed loop (Figure 1). The vector representation may invoke an image of a linked pathway which forms a complete balanced cycle. Now consider the same four vectors (same lengths and orientations as before) rearranged so that their tails are all connected to a common point (Figure 2).

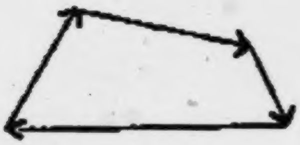


Figure 1: Vectors linked head to tail

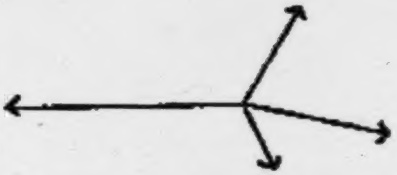


Figure 2: Vectors linked tail to tail

What image schemata are invoked for students when we tell them that this new vector representation is the same as the previous one and ask them to consider the whole as a collection of parts to be added together? Will the schemata invoked by students for balance, path, link, or cycle still be the same? In teaching about vectors we often view learners to be engaged in acts of abstracting away from experience. However, students may be engaging in a process of moving closer toward experience when they invoke image schemata in their processes of understanding scientific concepts. The understandings which arise from an individual schemata may be quite different from the understandings which emerge from the use of multiple connected schemata.

As Lemke (1995) points out, it is often the implicit embodied meanings of everyday language that cause conceptual difficulty for students rather than the scientific terms themselves. For example, what does positive and negative mean in discussions of vector diagrams, scalar diagrams, electrolytic cells, or attitudes toward school?

Johnson's argument for embodiment is based on the notion that our bodies and our symbolic meaning making processes are connected along some kind of experiential continuum. In The Tree of Knowledge, Maturana and Varela (1987) present a deeper argument for embodiment based on our evolution and our being in the world as biological organisms with a dynamic structure and organization which encompasses our physical and cognitive activities. In Maturana and Varela's (1987) notion of embodiment the microscopic physiological processes within the body and the macroscopic biological processes of the world form a holistic continuum. The cognizing human organism is not separate from its environment, it is an integral part of a larger dynamic whole. Meaning making is not only a cognitive activity; it is an enacted biological activity involving the organism, its history, and its environment in reciprocal shaping or mutual specification of each other.

In this research the idea of embodiment occurs in three possible ways: (1) as a vantage point for interpreting my observations of student action-thought in self-directed science activity; (2) as a means of sensitizing myself to the underlying meanings embodied in students' verbal descriptions of how they are thinking when they engage in activities; (3) as an agenda for myself as the researcher to engage in the actual doing of similar kinds of activities in order to develop a personal embodied understanding of what is involved in the development of student meaning.

Enaction

At a recent conference I participated in a simple demonstration of an optical phenomenon which yielded an unexpected result - one that is not explained by conventional presentations of the physics of light. The apparatus consisted of a collimated beam, a sheet of paper with a square hole near its center, and a surface (i.e. a wall) upon which the beam of light was projected. The sheet of paper was positioned in the beam so that light first passed through the hole before illuminating the wall. One typically expects the illuminated area on the wall to be a two dimensional representation of the shape of the hole in the paper. In the case of a square hole one expects to see a square shaped area. In fact, that is what you get when the paper is held perpendicular to the beam. However, when the paper is tilted away from that position the illuminated area on the wall appears to acquire new properties. The bright two-dimensional square area now appears to be transformed into a three-dimensional cube. How can this be? One expects the shape of the illuminated area to change as the paper is tilted but one does not expect his/her perception of a two-dimensional representation to be transformed into a three-dimensional representation.

The presenter (Reinhold, 1995) described this phenomenon as an example of a open-ended activity for secondary physics students. I was thinking about perception and representation. Encountering this phenomenon was an opportunity to explore further. I approached the presenter at the end of the talk and got permission to "play" with the apparatus. As I manipulated the apparatus and noticed how some changes seemed to cause certain effects I began to ask new questions and make new attempts to better understand this phenomenon through my actions. Ideas like forming a square hole out of four separate pieces of paper (each contributing an edge at different distances from the wall) or manipulating the light source or the beam collimator or changing the shape of the hole or introducing multiple holes emerged as my physical engagements with the phenomenon grew more complex. I was not only enacting my prior understanding of light, I was also enacting my current understanding of this particular phenomenon. Enaction was more than mere perception. It was perceptual action.

Consider the issues surrounding perception and representation. Varela, Thompson and Rosch (1991) , as does Merleau-Ponty (1962), argue that perception, not representation, is central to cognition. Such a view goes a long way to explain why students often fail to "see" the science in a laboratory activity even though they are doing things in an active way. Our cognitive structure/experience orients us to **observe** or in science, to **make** observations. It is thus not surprising that the science teacher and the students experience a phenomenon, say in physics or chemistry, in different ways. Being trained in science, the teacher sees the phenomenon as a scientific event. Many other aspects are bracketed out. The students, instead, may attend to all kinds of features that are "irrelevant" as far as the scientific point being made is concerned. They literally experience a different phenomenon (Fensham and Kass, 1988). Often pedagogic and scientific language complicate matters further. How is one supposed to, as physicists tell us, "ignore friction"? Why is phenolphthalein in a basic solution termed "pink" while litmus in an acidic solution is termed "red" when they both look very similar? As the phrase "to **make** an observation" implies what is being apprehended is more than just the environment, it is the outcome of a complex neurophysiological interaction **with** the environment - an enaction.

Context

Varela, Thompson, and Rosch (1991) emphasize that perception is a co-creation of organism and environment but they do not say much about the nature of the environment or context. Although they do not use the specific language of figure-ground, Varela, Thompson, and Rosch (1991) seem to make a distinction between person and setting. In other words, setting or context (environment) is described by what it is not. Thus setting becomes everything that is not defined to be organism. Varela, Thompson, and Rosch offer no specific help in distinguishing one context from another - after organism, everything else is environment. By placing most of their emphasis on the interaction between organism and environment (context), Varela, Thompson, and Rosch tend to avoid developing a clear description of the nature of either organism or environment (context). This may seem like a harsh criticism. Varela, Thompson, and Rosch take the organism as a "given" in the biologically evolutionary sense, a view I will consider in my subsequent commentary on structural coupling.

Lave (1988) places more importance to describing the nature of setting or context. She draws a clear boundary between setting and environment in the sense that she allows for the existence of many specific settings within an environment. Whereas Varela, Thompson, and Rosch (1991) would extend context to include everything in an environment, Lave (1988) draws a sharper focus for context. In doing this Lave (1988) introduces the idea of situated knowing within "arenas of action".

The nature of context from Lave's standpoint seems to be based on her research perspective as an observer of persons acting in settings. Once a particular context is described it remains fixed and the phenomenon of interest becomes the actions of the person operating within that context. Although Lave's (1988) unit of analysis is persons-acting-in-setting it seems that she considers setting to be the more stable component of that unit. I believe that this is a consequence of her role as an observer of action as opposed to an active participant in action. Is the nature of a context, in terms of its substantive description or its stability over a period of time, the same for an observer of an action setting as it is for a participant in that action setting? I intend to explore this issue by assuming, whenever pedagogically possible, the stance of a participant in my work with students as they engage in self-directed activity and to contrast this with situations where I am an observer.

This question raises a sticky problem in research involving people acting in settings. While it seems at first glance that Lave's superposition of persons, person's actions, and setting provides a coherent unit for analysis, it is not clear to me that this is the case. First, this unit of analysis assumes that persons acting together encounter a common setting. This seems problematic when considered from either the perspectives of persons-acting-together or person-acting-with-observer. Second, it assumes that a person's actions within a setting are as salient to the group as they are to the individual. Is context for an individual the same as it is for a pair of individuals working together? Can a person simultaneously act in accordance with a personal context and a shared context? Third, Lave's unit of analysis assumes that setting is relatively stable during a persons engagement with a setting. It allows action to emerge from context but it does not allow context to emerge from action. Lave asserts that problem and context emerge together but it is not clear that she intends that to mean that continued action within a problem-context can influence the nature of that problem-context. Context can not only be thought of as the background from which other phenomena emerge, it can also be thought of as being an emergent phenomenon itself. A view of context as dynamic and evolving seems implicit in the notion of **co-emergence** (see below).

Merleau-Ponty (1962) develops another different view toward the nature of context. He does this by describing the nature of the world as interpreted by phenomenology.

> The real is a closely woven fabric. It does await our judgment before incorporating the most surprising phenomena, or before rejecting the most plausible figments of our imagination. Perception is not a science of the world, it is not even an act, a deliberate taking up of a position; it is the background from which all acts stand out, and it is presupposed by them. The world is not an object such that I have in my possession the law of its making; it is the natural setting of, and field for, all my thoughts and all my explicit perceptions. (pp. 10-11).

Context becomes a woven fabric of thoughts and perceptions. Context is not an act of perception, it is perception. In this sense, Merleau-Ponty (1962) includes the person as an intrinsic and inseparable part of their world or context. This gives context a relational quality which depends on the persons who are included. Context also acquires a dynamic quality in the sense that the fabric of our perceptions and thoughts is constantly changing and being re-woven.

The question of where does meaning reside when a person is engaged in meaningful action in a setting can now be considered. Merleau-Ponty (1962) pointed out over thirty years ago that

> The phenomenological world is not the bringing to explicit expression of a pre-existing being, but the laying down of being. Philosophy is not the reflection of a pre-existing truth, but, like art, the act of bringing truth into being. One may well ask how this creation is possible, and if it does not recapture in things a pre-existing Reason. The answer is that the only pre-existent Logos is the world itself, and that the philosophy which bring it into visible existence does not begin by being possible; it is actual or real like the world of which it is a part, and no explanatory hypothesis is

> clearer than the act whereby we take up this unfinished world in an effort to complete and conceive it. Rationality is not a problem. There is behind it no unknown quantity which has to be determined by deduction, or, beginning with it, demonstrated inductively. We witness every minute the miracle of related experiences, and yet nobody knows better than we do how this miracle is worked, for we are ourselves this network of relationships. (p. 20).

It is clear that Merleau-Ponty situates meaning in the co-creation of knower and known - person and setting. Such a view challenges the notion of meaning as something which is transmitted in propositional form.

Coemergence/ Structural Coupling/ Adequate Conduct

The creation of meaning is an embodied and coemergent phenomenon. Understanding or meaning making is not about stepping out of and contemplating the world. It involves noticing how we are a part of the world and how we are connected to it. As Merleau-Ponty has pointed out:

> The phenomenological world is not pure being, but the sense which is revealed where the paths of my various experiences intersect and engage each other like gears. It is thus inseparable from subjectivity and intersubjectivity, which find their unity when I either take up my past experiences in those of the present, or other people's in my own. For the first time the philosopher's thinking is sufficiently conscious not to anticipate itself and endow its own results with reified form in the world. (p. 20).

The notion of coemergence raises the question of whether any activity, including that of science, is usefully viewed generically. If learning is an enactive and/or a constructive process that takes place in a contextual world, what is being enacted and/or constructed? The context in which the learning is situated becomes an important part of the picture. There are various types of science activity. Each calls for exploration of it's properties in the knowledge building of persons-acting on its own terms. Context and problem create each other (Lave, 1988; Chaiklin and Lave, 1993).

An enactivist perspective calls into question the functional status of any discrete or component part characterization of scientific thinking (or prescribed scientific method, scientific problem solving, and the like). Considered as situated in a particular context, the whole is more than its constituent parts. Criticisms in science education of the linear step by step approach to the description and evaluation of laboratory or practical activity are as yet few (Millar, 1991; Millar and Driver, 1987). On a practical note, I suggest that viewing a science investigative activity as an embodied whole allows one to examine the nature of its development from early to later stages, thus revealing aspects of the learning that takes place over its course. For me, learning and doing - normally separated as thought and action - are dynamically interrelated, as they are in scientific and technological work in out-of-school contexts. A more complete approach to the portrayal of science investigative activity recognizes that notions of personal and social knowledge and understanding involve multiple meanings about the nature of this reality as Merleau-Ponty (1962) put it, or of reason (Johnson, 1987), or of being (Maturana and Varela, 1987).

How do students go about doing science-related things in practical settings characterized by a high degree of autonomy in thought and action? What processes do students use in understanding what is involved and how do they go about the task as they extend and reinterpret it? How is such a potentially information-rich arena transformed into a specific activity-in-setting? I suggest (and this study explores) that students evolve their own meanings of, and actions for their knowledge building processes, in the science activities themselves and the investigations they enact, if given the opportunity to do so. Furthermore, processes of problem articulation/management are dialectic in nature, with progress toward resolution taking on both strategic and recursive elements.

If more than one person is involved, investigative work is also a social activity. Negotiation and communication are found to be present (Solomon, 1991) in collaborative investigative activity among very young as well as more mature learners. In these cases, as the problem and context coemerge, I can explore how the investigative task is enacted in the different contexts of the participants. I can also explore the co-construction of and shifting nature of contexts at the classroom teaching/learning level. What changes? What stays the same? In this way, different orientations to science, to knowledge and to learning may yield multiple accounts of the understanding process - a research agenda which deepens in scope progressively. Rather than arguing for one or the other perspective, I agree with Bruner (1986) when he suggests that there may be multiple world views which can be used to characterize a complex phenomenon like the development of understanding.

Structural Coupling

Maturana and Varela (1987) and Varela, Thompson, and Rosch (1991) talk about the term "structural coupling" as follows:

> The basic level of categorization, thus, appears to be the point at which cognition and environment become simultaneously enacted. The object appears to the perceiver as affording certain kinds of interactions, and the perceiver uses the objects with his body and mind in afforded manner. Form and function, normally investigated as opposing properties, are aspects of the same process, and organisms are highly sensitive to their coordination. (p. 177).

Merleau-Ponty identifies a process similar to structural coupling.

> Reflection does not withdraw from the world towards the unity of consciousness as the world's basis; it steps back to watch the forms of transcendence fly up like sparks from a fire; it slackens the intentional threads which attach us to the world and thus brings them to our notice; it alone is consciousness of the world because it reveals that world as strange and paradoxical. (p. 8).

My critical commentary here focuses on the notion of structural coupling. In any emerging understanding, the challenge is to "give voice" or "find voice" for the expression of initial ideas in a way that others can grasp enough of the notion to be able to engage in a discourse designed to clarify and refine the ideas. In this context, the choice of vocabulary in "structural coupling" seems to me to present several logical difficulties.

"Coupling" seems to imply the union of two discrete entities. This is not consistent with the idea of coemergence. It also flatly contradicts Varela, Thompson, and Rosch's (pp. 123-130) argument that there is no "self". If there is no "self" then what is there that is "structurally coupled" with the environment?" If there is only an "interconnected self" then how can one distinguish "figure" from "ground"? I am not disputing the idea of structural coupling that Varela, Thompson, and Rosch (1991) seem to be trying to express and illustrate with this term and their examples in evolutionary theory. Rather, I suggest that the choice of vocabulary and the images this choice evokes may need revision to express this idea more clearly.

How might a teacher encourage the emergence of an enactivist learning perspective among persons-acting-together in a classroom? Consider the following assertion from Varela, Thompson, and Rosch (1991):

> ... cognition is no longer seen as problem solving on the basis of representations; instead, cognition in its most encompassing sense consists in the enactment or bringing forth of a world by a viable history of structural coupling.
>
> It should be noted that such histories of coupling are not optimal; they are, rather, simply viable. This difference implies a corresponding difference in what is required of a cognitive system in its structural coupling. If this coupling were to be optimal, the interactions of the system would have to be (more or less) prescribed. For coupling to be viable, however, the perceptually guided action of the system must simply facilitate the continuing integrity of the system (ontogeny) and/or its lineage (phylogeny). Thus once again we have a logic that is proscriptive rather than prescriptive: any action undertaken by the system is permitted as long as it does not violate the constraint of having to maintain the integrity of the system and/or its lineage. (p. 205)."

If one substitutes "persons-acting-together-in-setting" for "system" then this statement suggests that there exist a wide range of effective structural couplings between person(s) and context? However, this issue is not really dealt with by Varela, Thompson, and Rosch (1991). I think that there probably is a variability in the possible levels of a structural coupling between person(s) and their environment but I think that it is likely perceiver-dependent. In other words, what may appear to be a strong or weak coupling from an observer (teacher) perspective may be quite different from a student perspective. I think that a person will see themselves as more or less strongly coupled to their environment (which in this study includes me as the researcher) depending on many things (e.g. - an action component to the engagement, the number and quality of the sensory connections to their social-cognitive environment).

In laboratory science I favor an approach which attempts to accommodate and improve the structural coupling between student and environment by providing multiple ways or affordances in which a student can couple to their environment. The focus is placed on how we "see" as opposed to "what" we see. In other words, what we "see" is always contextualized within the technique used to "see". This process can not be done if a "seeing" technique is chosen for the student and/or only one technique for "seeing" is available. I like a laboratory environment which allows students' own preferred techniques of coupling to an environment to emerge. The common practice of preparing materials for students before they engage in a lab activity constrains this sort of thing. I think it would be interesting to see what materials and strategies students would suggest are necessary for a given investigative task. As the action-context for my research I have sought classrooms in which the students are engaged in science activities which have a strong element of self-direction in establishing the parameters of the task and the materials/procedures to be used. The secondary science curriculum in Alberta provides for such activity and numerous local teachers use them as part of science learning.

Adequate Conduct

The issue of **adequate conduct** is relevant to most perspectives on learning and teaching. In this regard I am assuming that learning and teaching are intentional acts. Under that assumption it makes sense to say that learners and teachers are concerned with what constitutes adequate conduct on their own part or on the part of others. What do I mean by adequate conduct? Adequate conduct in processes of meaning making simply refers to any actions which allow for understanding to occur. If one adopts a process-oriented, as opposed to a product-oriented, approach to learning then adequate conduct refers to any actions which allow processes of learning to occur.

But adequate for whom and in what sense? This term can be applied at many levels. For instance, one might address "adequate conduct" from the perspective of the individual learner, a group of learners acting together, a researcher/teacher and learner acting together, or an entire classroom. I am interested in developing deeper insights into how adequate conduct can be identified, described and encouraged.

A key point in the Varela, Thompson, and Rosch (1991) argument regarding evolution also has fundamental implications for cognition and, hence, for learning and teaching:

> "The first step is to switch from a prescriptive logic to a proscriptive one, that is, from the idea that what is not allowed is forbidden to the idea that what is not forbidden is allowed." (Varela, Thompson, and Rosch, p. 195)

Western orientation to cognition is not comfortable with the presence of contradictory ideas or interpretations within the same context. If such a state of affairs should arise, the immediate motivation is to resolve the contradiction. Festinger's theory of cognitive dissonance (Festinger, 1962) is among the best known of such psychological theories. The "discrepant event" strategy in inquiry teaching approaches to science is predicated on the theory that recognition of discrepancy/dissonance provides in itself the impetus for cognitive change. With the notable exception of Piaget (according to von Glasersfeld) most Western modernist approaches to cognition rest on the ideal of an ultimate "correct" or "true" answer. Indeed, our whole notion of authority is based on this idea.

Teaching science and mathematics, according to such a view, is about mastering correct procedures to arrive at true answers. The depth to which this view is ingrained is reflected in the often expressed statement (by both teachers and students) that an experiment "didn't work" i.e. that attempts that don't work out as expected, yield wrong answers. This is the prescriptive view of nature and of school science.

In a proscriptive view there is no concept of experiments "not working". All experiments work. Nature always "works". Nature is not correct or incorrect—nature simply **is**. Human designs and strategies may be successful or unsuccessful in meeting the conditions of nature in specific instances (c.f. Varela, Thompson, and Rosch's 1991 treatment of intentionality on p. 205). This is a shortcoming in human interpretation and/or cognition, **not** a shortcoming in nature. Learning and teaching become co-evolving processes of understanding in which a dynamic environment is mutually established and allowed to drift as new enactions emerge. Such a view seriously challenges the notion of a generic student. It allows for the coexistence of qualitatively different starting points and directions for the development of understanding by individual students—a very different context for teaching than one implied by the prescriptive view of nature and of school science.

> ... intelligence shifts from being the capacity to solve a problem to the capacity to enter into a shared world of significance (Varela, Thompson, and Rosch, p. 207)

This is a powerful statement. Shared by whom? Shared in what sense? When a pair of students and a researcher/teacher work together in a problem setting, what constitutes adequate conduct for the three people inside the group, or for a fourth person observing from the outside?

I am intrigued by Varela, Thompson, and Rosch's (1991) statement that "...closure and coupling suffice to bring forth a world of relevance for a system (p. 156)." This is connected to:

> cognition is no longer seen as problem solving on the basis of representations; instead, cognition in its most encompassing sense consists in the enactment or bringing forth of a world by a viable history of structural coupling ... such histories of coupling are not optimal; they are, rather, simply viable (Varela, Thompson, and Rosch, p. 205).

I will explore the conditions under which proscriptive classroom learning/teaching environments emerge and become viable, and their implications for how students conceptualize their actions within their learning engagements.

Common-sense Knowledge

Bruner (1986) distinguishes between two forms of knowledge: procedural knowledge and narrative knowledge. Once one accepts that there are multiple ways of knowing then it becomes easier to consider common-sense forms as being relevant to science learning.

> "If, however, our lived world does not have predefined boundaries, then it seems unrealistic to expect to capture commonsense understanding in the form of a representation - where representation is understood in its strong sense as the re-presentation of a pregiven world. Indeed if we wish to recover common sense, then we must invert the representationist attitude by treating context-dependent know-how not as a residual artifact that can be progressively eliminated by the discovery of more sophisticated rules

> but as, in fact, the very essence of cognitive creation (Varela, Thompson, and Rosch, 1991, p. 148)."

Despite the above assertion, Varela, Thompson and Rosch (1991) seem somewhat superficial in their treatment of commonsense knowledge, characterizing it as merely "background know-how" (p. 147). This area is complex and subject to at least two different interpretations depending on whether it is the "common" or the "sense" aspect which is being emphasized. Except for a few vague illusions to "folk psychology", little grounding is provided by Varela, Thompson, and Rosch (1991) for global assertions such as that we must treat "context -dependent know -how... as, in fact, the very essence of creative cognition (p. 148)" and that "common sense is none other than our bodily and social history ... (p. 150)". What is meant by "creative cognition"? How is "context-dependent know-how" related to common sense know-how?

The tendency to leave terms vague tends upon closer examination to make a number of nominally incisive statements rather vacuous. The above statement about the "essence of creative cognition (p.148)" is a case in point. Another is:

> knowledge is the result of an ongoing interpretation that emerges from our capacities of understanding. These capacities are rooted in the structures of our biological embodiment but are lived and experienced within a domain of consensual action and cultural history. They enable us to make sense of our world; or in more phenomenological language, they are the structures by which we exist in the manner of "having a world" (Varela, Thompson, and Rosch, p. 150).

What is meant by "understanding" and "capacities for understanding" in this discourse? At the curriculum design level, the implications are quite clear: cognition involves enaction, providing strong support for the positioning of activity oriented curricula and teaching approaches at the center of schooling. It also implies that transmission approaches to teaching and curricula which emphasize verbal and symbolic "knowing that" at the expense of "knowing how" lead to sterile and nonfunctional compilations of information rather than functional understanding. Varela, Thompson and Rosch (1991) would likely approve of some of the current orientation of grades 7, 8, 9 science and Science 10, 20, 30 (grade 10, 11, 12 science) in Alberta. Students engage in sequences of science and technology related activities which provide experience with the phenomena in question and permit (within limits) exploration and creative problem solving. Learning, however, is still viewed as the outcome of such engagements.

How is Understanding Enacted?

Andersson (1986) describes an underlying experiential gestalt of causation which represents a common core to the reasoning employed by children. A given gestalt consists of a number of different components which together form a whole that is greater than the sum of its parts. Is there evidence of an experiential gestalt in student self-directed investigations? This is a question I consider useful because it may reveal evidence for a larger more holistic aspect of an investigative sequence which can not be addressed by a "process skills" analysis of the separate parts of the investigations. Is a "bringing forth" of the world implicitly coherent?

I suspect, although it is very difficult to identify, that some students develop a sense of "pattern building" as they move through an investigative sequence or develop a tendency to divergent thinking by switching strategies during their investigations. For instance, students may learn that it can help them if they periodically switch strategies from focused action to unfocused play during an investigation. It may be that students would progress even more effectively through an investigative sequence if they were given a second opportunity to engage in another open-ended activity or investigation similar to one they had just completed. It would be worthwhile to engage student groups in a series of open-ended investigations with the goal of looking for evidence of similar strategies over individuals and settings and improvement in investigative approaches. For instance, do students who seem to prefer improvisational sequences as precursors to more focused action continue to employ this approach in other open-ended activities?

There is a very good chance that students can learn something quite powerful from their engagement in the whole investigative sequence that is more compelling than anything they can learn from their engagement in any single part of it. I think it is worthwhile to ask students if and what they felt they learned as a result of their engagement in open-ended self-directed activities.

McClelland (1984) has raised the issue of salience in engagement activities. McClelland states that unless an activity leads a student to theorize about the phenomenon involved in the activity it can not be considered a scientific activity. Kuhn, Amsel and O'Loughlin

(1988) take a similar position. While I agree that theorizing is a necessary component of science I think it becomes problematic when one attempts to distinguish between activities which include theorizing and those which do not, based on inferential evidence from an outside observer. In other words, how is theorizing enacted by people? Is it possible that certain kinds of action are one form of theorizing? My view is that it is important to be open to how "scientific" behaviors might appear to an observer or participant in forms which differ from how we traditionally view them as occurring.

Helanko (in Van Aufshnaiter and Schwedes, 1989) defines play as an activity which is self-determined due to her/his own perception, and which is pursued without external interference. Helanko maintains that every individual is inclined to transform non-play systems into play systems , i.e. to transmit given external objectives and actions by way of identification and modification. According to Helanko, learning (meaningful learning) predominantly takes place in play systems, or whenever non-play systems are transformed into play systems. It must be emphasized that this play process is subjective and individual, and that the individual takes an active part in all learning processes.

Play orientation does not mean that games predominate. It means that the teacher provides students with opportunities to act and think independently during instruction. It also means that direct teaching engagements are planned with the intention of enabling students to build up new play systems.

Woolnough(1991) offers another definition of play in which he identifies three types of activity: (1) play to build up interest and basic familiarity; (2) practice to build up basic competencies and confidence; and (3) exploring to challenge, and extend frontiers. A learner needs to be continually moving from one type of activity to another.

Sensory (especially visual) evidence appears to have a rather profound impact on students as they engage in playful and exploratory action. It is important to distinguish this holistic notion of the visual from the more traditional (process skill) perspective of the visual. In a process skill perspective, emphasis is placed on obtaining a high degree of resolution and specificity from an observation. It is a deductive enterprise in that the students seek to narrow and sharpen their focus. A student with a more holistic view of observation "notices" many different things but does not necessarily focus immediately on any one. Emphasis is placed on getting a sense of the diversity of the phenomenon and a "feel" for some of the boundaries and connections which are embodied in the phenomenon-person system. It is a more inductive enterprise in that students seek to broaden and extend their focus. I will attempt to capture some of these "acting-moments" in my descriptive interpretive portrayals.

Learning: Enactivist and Constructivist Views

Constructivism deals with questions of the nature of knowledge - what is knowledge and where does it originate? In the past fifteen years a dominant research paradigm has emerged in cognition and learning in the field of science education. It is widely described as "constructivism". While grounded in the ideas of Piaget and Ausubel the impetus for a great deal of empirical work has been the attempt to identify and catalogue the misconceptions, preconceptions, naive theories, and/or alternative conceptions (Driver and Easley, 1978) of students at various levels about various topics in school science. A data base listing these studies (Pfundt and Duit, 1991) is currently in its fourth edition and contains thousands of titles.

The establishment of a common research focus under the rubric of constructivism has, to some extent, accomplished the following:

1. It has attracted a large number of researchers from a wide range of developed and developing countries thus establishing an international research community.

2. It has established a common vocabulary for describing and interpreting its research findings.

3. It shares a theoretical interpretive framework in that it views knowledge as an active construction by a person.

4. It has developed a relatively forthright set of research procedures which can be broadly grouped into two categories: (1) interview about instances (Osborne and Gilbert, 1980; Posner and Gertzog, 1982; Osborne and Freyberg, 1985) and (2) predict-observe-explain (White and Gunstone, 1991).

What constitutes the domain of constructivism? Is it an epistemological orientation, a psychological orientation, a pedagogical orientation, or a combination of these? As in any complex and large research community there are "within group" differences regarding the nature of constructivism. Views range from a radical constructivist perspective (Von Glasersfeld, 1984, 1995a, 1995b) to a social constructivist perspective (Vygotsky, 1978, 1986; Wertsch, 1991; Wertsch and Toma, 1995).

Most empirical studies in science education have tended toward a social constructivist interpretation (O'Loughlin, 1992). Implicit in the research approach is the notion of a correct scientific interpretation against which students responses are assessed. What is considered as a correct scientific interpretation would be referred to as a component of a scientific paradigm (Kuhn, 1970) or as adequate conduct (Varela, Thompson, and Rosch, 1991). Furthermore, implicit in the sociocultural view is the pedagogic goal of teaching for conceptual change (Driver and Easley, 1978; Driver, 1981; Hewson, 1981; Driver and Erickson, 1983; Driver and Bell, 1986; Fensham, 1988; White and Gunstone, 1991), which has spawned a pedagogic approach known as constructivist science teaching (Posner, Strike, Hewson, and Gertzog, 1982). Discussions about the nature of constructivism as a theoretical position constitute a small part of the published research in the field of science education. (This is an interesting difference from mathematics education research where the theoretical nature of constructivism is hotly debated.) Perhaps , as pointed out by Cobb (1994), the radical-social constructivist debate is a false issue in that the two views of constructivism complement each other. Cobb resolves the issue in a figure-ground sense in that he advocates thinking about each view as emerging from the other in a complementary way. Cobb (1994) asserts that "the sociocultural and constructivist perspectives each constitute the background for the other (p. 19)."

The constructivist research program has been useful in making science educators aware of the range of alternative ideas that students have about a variety of topics in science such as gravity, heat, energy, force, light, the structure of matter, motion, evolution, genetics and others. Knowing about the range of ideas that can exist in a classroom of learners is one thing; how to stimulate the learner to adopt a view which is consistent with a scientific position is something else. Early approaches to conceptual change stress the importance of confronting the learner with the discrepancy between his/her own ideas and a scientifically acceptable position (Posner et al., 1982). Empirical studies which have attempted to bridge the gap between a personally held conception of an individual and the scientific view have in general revealed that the conceptions of an individual are extremely difficult to change. Even when conceptions are apparently changed in a school setting, earlier conceptions can quickly reassert themselves in the contexts of further schooling or of the everyday world. Two common examples are an Aristotelian versus a Newtonian view of motion (Clement, 1982) or thinking about heat as a flowing substance as opposed to molecular motion (Erickson, 1979, 1980).

A number of writers (Fensham, Gunstone and White, 1994) are now suggesting that a direct confrontational approach to conceptual change may intimidate students rather than providing the hoped for stimulus for conceptual reorganization. There is an argument to be made in favor of a more gradualist view to conceptual change. For instance, Fensham, Gunstone and White (1994) talk about evolutionary as opposed to revolutionary conceptual change. Some writers such as Solomon (1994) have gone as far as to say that the lack of a direct pedagogic strategy within the constructivist orientation is a mark of its failure.

Despite its limitations I think that the constructivist orientation has yielded some very useful pedagogic approaches. For instance, White and Gunstone (1991) describe techniques for probing student understanding which can be used as both research and teaching instruments. Among these are concept mapping, interview about instances, predict-observe-explain and fortune lines. While one would hope that research findings can translate into pedagogic practice, the route of such influences is often more complex than first appears. I regard the approaches developed within the constructivist research program in science education (Bell and Pearson, 1992) as useful observational techniques both within the contexts of science education research and science teacher education. However, the pedagogic problem is that these are generic techniques which rely for the most part on the teacher, not the student for their successful implementation. One notable exception is the work on metacognition developed by Baird (1988) and Baird and Mitchell (1986) in which some of these techniques are used by students in order to make themselves aware of their own cognitive functioning. By and large the use of the techniques relies on student verbalization of her/his ideas which are then interpreted by the researcher/teacher in a representationist way. In other words, it is assumed that how students use language is a direct mirror of how they are thinking about the phenomenon selected for them by the teacher. It is also possible that peer pressure will influence a student to verbalize a conception which is not consistent with what he/she really thinks. I have argued earlier that how an individual perceives a task is a complex creation of persons-acting-in-setting.

Techniques such as interview about instances or predict-observe-explain involve both the researcher and student in structured roles. From a student's perspective these activities are initiated and modulated by the researcher. The student's conception of the nature of the interaction between herself/himself and the researcher may play a significant role in how to engage and think about a phenomenon and it influences what is revealed. An enactivist research approach, on the other hand, may have the potential for allowing a more natural interaction to emerge in that the idea of adequate conduct by teacher and student(s) (see p. 34) allows for a range of meaningful and viable actions and interactions to be expressed. This goes to the validity of the data that are obtained (issues of validity and reliability will be addressed in Chapter 4).

Constructivism involves a perspective on the nature of knowledge and a view of the nature of the student. A student is viewed as a person who is actively involved in creating his/her own personal knowledge which has individual meaning. Knowledge is considered to be held by or to exist within a person. The goal of the constructivist science education researcher is to engage students with phenomena in such a way that they will reveal knowledge which they hold. The purpose of the research engagement is to act as a conduit for information about what the student knows to be passed from the student to the researcher. There is a clear separation in the kinds of actions in which the researcher and the student are allowed to participate.

In viewing knowledge as existing within a person the constructivist researcher tends to neglect the role of context or setting in the construction of knowledge. Tasks are typically simple natural phenomena devoid of context and presented as simple demonstrations with everyday materials. Tasks may also consist of line drawings involving stick figures and cartoons (Feher, 1990; Shapiro, 1994) or films (Aguirre and Erickson, 1984). The student is rarely encouraged to explore or modify the stimulus situation in any way or to add her/his own representations of the phenomenon and the setting. Often the response format involves the student in picking a correct answer from a set of multiple choices. If we recognize Lave's (1988) claim that knowing involves intelligent action within a setting, then what is revealed about knowing in context-sterile situations such as the ones just described? In recognizing that the creation of meaning is an embodied contextual occurrence, an enactivist view expands and problematizes the notion of what it means to be a researcher with a student in a particular setting.

One consequence of ignoring context has been that constructivist researchers tend to overemphasize the importance of verbal description in revealing student understandings. What students write or say is assumed to reflect in a direct way what they understand about a particular phenomenon that the researcher considers important. However, the phenomenon which is noticed or described by a student is not necessarily the same as the one intended by the researcher. In fact, the phenomenon which most influences a student may be his/her understanding of the research setting. For example, researchers interviewing students about instances have at times formed the impression that students create their conceptions in the course of the interview rather than revealing any preexisting understandings. This uncertainty may be reflected in the lack of consensus among the research community about whether one is studying preconceptions, misconceptions or alternative conceptions (Driver and Easley, 1978). If a student has never thought about gravity until (s)he is engaged in a research interview then what is being revealed? Is it personally held views, conceptions, meanings and understandings or is it something else?

When constructivist researchers do consider setting or context they tend to draw a boundary in such a way that they are outside that boundary. If and when they do consider themselves to be a part of a setting they tend to attempt to minimize or explain away their role in the setting. Constructivist researchers tend to view students as the creators of action and themselves as the observers of action. In adopting this view, constructivist researchers attempt to minimize their engagement with the person, the setting, or the phenomenon. Thus, a second consequence of the view that knowledge is held within an individual is that a constructivist research approach tends to ignore the role of the researcher in the construction of knowledge in a setting. As already noted my research orientation is one in which the researcher is a participant in the developing setting or context.

The foregoing comments on constructivism are not intended as a thorough analysis and critique of this complex research program. Rather I have touched on some of its features in contrast to key ideas of enactivism. Good et al (1995) caution against the uncritical adoption of novel theoretical positions in areas of cognition and learning. I do not consider enactivism to be another "ism" in opposition to constructivism. In fact, I prefer to think of constructivism and enactivism as cognitive perspectives rather than cognitive theories. Viewed as perspectives, constructivism and enactivism offer different (but not separate) ways of acting toward and interacting with the action-thought worlds (i.e. persons-acting-in-setting) researchers attempt to explore and understand.

The constructivist metaphor of the knower as an active creator of his/her knowledge seems to me to be powerful and provide an important area of overlap for the two perspectives. What I am attempting to do is to contrast a vantage point on **knowing as intelligent action** as reflected in the views of enactivist theorists with that of some of the implications of constructivist views. Table 1 presents a summary of some of the points I consider important. The descriptive phrases in the two columns are not intended to identify categories. Rather they describe positions that distinguish various features of enactivism and constructivism.

Table 1

Vantage Points on Constructivism and Enactivism

Constructivism	Enactivism
Views knowledge as existing within a person	Views knowledge as existing in the coemergence of a person and their world
Views understanding as being expressed in explanations and theories	Views understanding as being expressed in embodied action
Focuses on verbal/symbolic aspects of cognition (thinking is done by minds)	Focuses on embodied cognition (thinking is done by a person-in-her-world)
Learner rationalizes, evaluates and decides whether to reconstruct or add to existing cognitive structure	"laying down a path in walking" coemergence of person and setting
Learner/teacher/researcher are independent Learner engages in learning Teacher engages in teaching Researcher engages in observing	Learner/teacher/researcher are complicit in learning/teaching Each participates in other's action Actions of others has meaning for each
Representationist, decontextualized (explanations/theories)	Non-representationist, contextualized (acts)

I now return to the five questions that have guided my journey through the ideas cited in this chapter.

1. What is the nature of knowing?

In my study I address this question from the position that knowing is an embodied process.

2. How does knowing or understanding emerge?

My starting point here is to say that embodied action plays a central role in processes of knowing or understanding. A goal of my dissertation is to provide interpretations of aspects these processes as I experience them.

3. Where does meaning reside?

I consider meaning to be a coemergent phenomenon. It resides in the actions and interactions between individuals and phenomena. My engagements with students as we enact our understandings will examine aspects of personal and collective construction of meaning.

4. How is understanding enacted?

A focus of the empirical component of my study is portraying how understanding is enacted.

5. What can enactivism contribute to our understanding of knowing/understanding?

I consider enactivism to provide a perspective for **engaging** in action-thought and a perspective for **interpreting** action-thought. In other words, because enactivism is both a theoretical and a methodological position, I think it has the potential to contribute to our understanding of knowing/understanding from the perspectives of students, teachers, and researchers. I am challenging and testing the ideas of enactivism as I use it as a framework for the interpretation of action and of knowing and as a way of choosing my own action in research settings.

Attending to the process of coming to understand from an enactivist perspective both problematizes and illuminates aspects of science doing and learning. It problematizes in the sense that the research coemerges in reciprocal specification with student enaction in bringing forth their world. One process is embedded and held in relation to the other within the overall situatedness of the endeavor. Both have implications for revealing the nature of practice. I am intrigued by the possibilities inherent in these metaphors as ways of capturing holistic aspects of such thought-action patterns.

What is the nature of coming to understand in expressive environments in which students are, within reason, given the latitude to do what they want to do? The power of a proscriptive stance to generate possibilities is illuminating. When students act according to the implicit guideline that "what is not expressly forbidden is allowed" rather than "all that is not specifically allowed is forbidden", the range and diversity of thought and action that is revealed has the potential to be rich and complex. Persons-acting who focus on what they can do instead of on what they cannot do demonstrate to themselves and to others that their understanding is in their doing.

I now turn to questions of schooling and performance assessment in order to present a rationale grounded in pedagogic practice. In particular, I address the issues which involve performance assessment to which my research is directed.

Chapter 3: Practical Rationale

> *An invention is the technological analogue of a theory in science. Treating the act of invention as a cognitive process exposes some remarkable lacunae in our understanding of what is involved. (Layton, 1991, pp. 74-75)*

I will now consider implications of an enactivist perspective in terms of issues of curriculum, pedagogy, and assessment. Current curricula, in which Alberta has been a participant in the recent wave of reform, emphasize student activities in which students are expected to be skilled in self-directed activity involving building and devising practical solutions to technological and environmental challenges. Teachers are called upon to devise, oversee, and provide leadership in a range of complex projects that call for changed thinking about what is involved in the pedagogic relationship and in the assessment of student performance and understanding.

Performance assessment is a "hot" topic in science education today. Provincial ministries such as Alberta Education are devoting resources which in former years were devoted to curriculum development to the establishment to national performance bench marks against which students, school systems, and programs are to be evaluated. The creation of the Western Canada Protocol and a national assessment project conducted under the Council of Ministers of Education attest to the importance placed on obtaining and monitoring bench mark data on the performance competencies of Canadian youth. As a result of studies such as the Second IEA study, (Connelly, Crocker, and Kass, 1985, 1989) and various OECD studies, policy makers, science educators, and business leaders have become increasingly interested in how the science knowledge and understanding of Canadian youth compares with that of other industrialized countries.

Science education researchers have long been interested in questions about the nature and development of problem solving skills of students and in how students engage in science investigations (Kuhn et al., 1988; Carey, 1989). Various performance assessment strategies have been implemented in England, Australia, Israel, and elsewhere. In England, the Assessment of Performance Unit (APU) (Driver et al., 1984) played a significant role in influencing teachers, researchers, and curriculum developers around the world to include extended investigations and hands-on tasks in their approaches to assessment. The more recent British Columbia science assessment (Erickson et al., 1991) was strongly influenced by the APU's approach to practical performance assessment and included a component in which teacher-observers monitored students' activities over the entire course of their extended investigations. Curriculum developers in Alberta have recently taken notice of this body of work and Alberta Education is currently field testing performance assessment instruments around the province. It appears, however, that Alberta Education intends to view student performance as a construct which can be measured as an outcome of a process rather than something which needs to be evaluated as it occurs in process.

The purpose of this chapter is to examine issues surrounding questions involving the nature and use of practical action by educators as a context for assessing student understanding. A central purpose of my study is to address the following question: **how do students use practical action to gain meaning and understanding in science classrooms?** Performance assessment attempts to interpret student practical action in order to assess understanding. Implicit to such assessment are the assumptions that educators know what practical action is, how it can be used to engage students in adequate conduct, how it can be interpreted, and what meanings it holds for students. Issues surrounding these assumptions and the questions they raise have been generally ignored by test designers in their rush to implement alternative forms of assessment such as performance assessment. It is these issues and the questions which emerge from them that I will now address.

What are the Purposes of Practical Activity in Science?

According to a pre-eminent proponent of meaningful verbal learning:

> Science courses at all academic levels are ... organized so that students waste many valuable hours in the laboratory collecting and manipulating empirical data which, at the very best, help them rediscover or exemplify principles that the instructor could present verbally and demonstrate visually in a matter of minutes. ... Primary responsibility for transmitting the content of science should be delegated to teacher and textbook, whereas primary responsibility for transmitting appreciation of scientific method should be delegated to the laboratory (Ausubel, 1968, p. 345).

The above statement captures the tension between telling and doing that continually faces the science teacher in planning instruction. Should one start with action or with verbal explanation? What kind of balance is appropriate for the learning goals to be achieved?

Recommendations of science educators are not consistent on these matters. For example, Woolnough and Allsop (1985) argue that a "tight coupling of practice and theory can have a detrimental effect on both the quality of practical work done and on the theoretical understandings gained by the students" (p. 8).

As science curricula become more and more tightly packed in the kinds of knowledge students are expected to acquire, laboratory work, if included at all, is restricted to illustrating and verifying the textbook material. This tendency becomes increasingly more pronounced at the senior levels of secondary schooling. One reason for choosing to work at the middle school level in my research projects is that one is more likely to encounter settings where all the students are encouraged to explore and develop their own ideas through an assortment of projects.

What purposes are served by practical work? This question has been addressed in a number of different ways by science educators. Tamir (1991) has summarized the purposes of practical work as it is currently viewed by science education researchers around the world. The purposes Tamir identifies are to: (1) develop an understanding of science concepts, (2a) develop inquiry skills, (2b) develop particular practical skills, (3) engage students in science activity that is qualitatively different from non-practical activity, (4) identify, diagnose, and change the alternative conceptions of students, and (5) motivate students. Millar (1991) claims that it is the first two of these purposes which are most often used to justify the use of practical work. Millar (1991) argues that while practical activity can facilitate (1) and (2b), it cannot be used to teach (2a - the separate intellectual inquiry or process skills) successfully. Millar's position is that practical activity should be used to promote the development of a general set of inter-related practical skills which he refers to as procedural understanding. An enactivist position would support Millar's contention in that investigative activity is considered holistic in nature and involves cycles of progression and recursion.

Implicit in these arguments is the assumption that understanding and practical activity are distinct categories. I do not agree with this position. As stated earlier, my view is that **practical action is not a precursor to or an outcome of understanding, it is a form of understanding.** Problem development/solution and intelligent action are contextual. Kuhn (1970) points out in The Structure of Scientific Revolutions that formalisms of science are "law-schema". It is the experience of working them out in real contexts that provides their content and, hence, understanding. The meanings of key terms associated with science are embodied (Johnson, 1987) and need to be experienced in order to be understood. "Qualities we cannot experience, we cannot know." (Eisner, 1988, p. 15). The quotation from Layton (1991) which appears at the beginning of this chapter supports this view. The purpose of practical activity in science is not to be used as a means to an end, it is its own end.

My consideration of the purposes of practical activity in science needs to include the perspectives of students. What purposes do students consider practical action to have for themselves? Students and teacher/researcher may not consider practical action in the same way. Developing a richer and more complex understanding of how students create meaning and understanding in practical action is a central goal of my study.

Issues in Performance Assessment

For two years I taught a pre-service teacher education course in science for students who were destined to be teachers at the elementary level. Most of the students in this group had very little formal science experience in their educational backgrounds. I decided to include a performance component to this course. Students would conduct a "science investigation" and report their results to the rest of the class. Each student could choose to study anything (s)he liked and a ten week period was negotiated as being sufficient to complete the work. I was unsure at the beginning about how I would evaluate their performance, but I handed out a standard checklist style evaluation form which was similar to many I had used at science fairs. This checklist divided the total grade for a student's performance into discrete categories related to such things as quality of display and several science process skills.

I was unprepared for the level of anxiety this task inspired in my class. Students were tearing their hair out trying to think of ideas and eventually I decided to provide several examples of "appropriate" choices. Ultimately the whole thing became a very product oriented event and I completed my checklist evaluations so that all the student performances could be "assessed".

Most students were quite pleased with the outcomes of their work. The collection of presentations filled a large room and made a rather impressive display. Experiences such as this coupled with my history as a judge in school science fairs cause me to question how I measured the performance of students in extended investigative activities. Does the final product represent the cumulative performance of the students who prepared the display? After the assessments were completed I spoke to many of my students about their experiences during the project. I found that students' descriptions of their explorations were far more exciting and interesting than what they chose to present in their final reports. I discovered that many students whose work I decided to be below average had, in fact, conducted some extremely intuitive and imaginative trials which they did not report because they felt they were not satisfied with the outcomes produced. Every conversation included descriptions of ideas, failed attempts and struggles to retool an approach which were part of the untold story associated with a student's thinking. It became apparent to me that I had not assessed the scientific actions of students. Rather a large component of my evaluation judged their abilities to organize and retrospectively report data scientifically and, ultimately, to produce a finished product. I decided to explore these issues further in my research engagements with students in the present study.

Performance Assessment

There are many ways in which educators can assess students. Each of these involve observing some form of student "performance". Students' observable "performances" can include a written, spoken, or an action component which may give measurable evidence of thinking and learning. Traditional forms of assessment have tended to focus on the verbal domains by assessing what students say or write. For instance, students are asked to demonstrate their ability to "perform" a cognitive task when they are given a pen and paper test. While it is the case that some people could describe this as an example of performance assessment where students are asked to convert thought activity into writing "action" I would like to re-examine the issue of "performance".

Woolnough (1991) points out that many students seem to require immediate experience in order to be successful in a task. Pen and paper activities usually require a student to begin a task with thought before writing and do not include a manipulative component. Consequently, I do not consider pen and paper tasks alone to be adequate assessments of performance in the context of science education. Performance, in my view, must not only contain a forward linkage between thought and action it must also include a recursive linkage between action and thought. In other words, action-thought forms a connected loop or cycle. Furthermore, in my estimation, the action component of a test or activity must contain an opportunity to manipulate more than just pen or paper - i.e., materials or equipment - in order to qualify as a science performance activity. One reason for this requirement is that it is not obvious to me that all students can successfully engage in a task by beginning at the thought stage of the action-thought cycle.

Questions pertaining to what students do, what they think they do, and what they learn when engaged in investigative science-related activities are important within the current reconceptualization of science teaching (Woolnough, 1991; Fensham, White and Gunstone, 1995). What does it mean to understand science and how can understanding be revealed at various school levels and in various disciplinary contexts? Reconceptualizations of science curriculum (Fensham, 1988; Fensham, White and Gunstone, 1995) reinforce the notion that it is important for science students to know how to do science-related things in various practical settings. When multiple and sometimes competing outcomes are sought, the context in which learning is situated becomes an essential part of the picture. It is no longer useful to view science activity in generic terms. There are various types of science activity, and the contributions to knowledge-building of each require examination on its own terms and in its own contexts.

In addition to the need for a broader base for student assessment to coincide with the changes in emphasis of contemporary science curriculum, two other factors are seen as contributing to the current interest in performance assessment. International and National assessments carried out in various countries including Canada (Connelly, Crocker and Kass, 1985, 1989) have indicated that students performance is not adequate for today's technological needs in society. Performance assessment is a response to this perceived shortcoming. A second contributing factor is related to the current increasing involvement of business and industry in educational partnerships and policy setting. Performance is widely used in the business world as an evaluative tool to promote productive change. The movement of ministries of education toward performance assessment as a means to responding to public demands for accountability seems consistent with the motivation of business and industry toward this form of assessment. Provincial ministries of education - e.g. Alberta and British Columbia - are currently implementing a science performance component at selected grade levels in order to assess students' attainment of curricular goals.

In this chapter I will describe various approaches to performance assessment and examine some of the issues surrounding these approaches within the context of current initiatives in Alberta and British Columbia. I will also present some of the current thinking surrounding validity issues in performance assessment in relation to the purpose of my study. I argue that the question of what a holistic evaluation strategy is, and how it could be applied, depends not only on how one conceptualizes performance but also on the purpose for which the assessment is intended. I suggest that the degree to which performance assessment tasks place emphasis on describing the "scientific" nature of a student's investigative process is not of central importance in portraying the depth and complexity of his/her understanding.

Practical Science Activity

Woolnough (1991) identifies three types of practical activity in school science - exercises, experiences, and investigations. Activities designed to develop a particular skill - e.g. measurement, familiarity with apparatus like a microscope, or proficiency with procedures such as titration - may be termed **laboratory or practical exercises**. This category of activity is conceptually related, perhaps unfortunately, to the process skill approach to science education (American Association for the Advancement of Science, 1967) found in many curricula, including that of Alberta.

Activities designed to acquaint students with selected scientific phenomena may be termed **laboratory or practical experiences**. Measuring the speed of rocket cars, experimenting with various chemical equilibrium situations, and examining life forms collected from pond water build a base of personal knowledge and understanding for the student which is the basis for future action learning. The majority of secondary school laboratory activity is of this nature.

Woolnough's third category of activity is termed **laboratory or practical investigation**. Investigations are characterized by continual modification through feedback of action-thought which accompanies the testing of ideas and the development of understanding of an authentic problem (Roth, 1995).

Self-directed investigation is an important component of performance assessment strategies in that it views student activity in a holistic way. Criticisms of the discrete or component part approach to the description and evaluation of laboratory or practical activity have appeared in the literature (Millar, 1991; Millar and Driver, 1987). In chapter two I argued from an enactivist perspective that the whole is more than the sum of its component parts, particularly when considered as situated in a specific context. Including fairly extended investigations as part of performance assessment allows one to assess the nature of the process as it evolves over a period of time. Aspects of student understandings that are not apparent in school practical exercises where time is a dominant constraint are given an opportunity to emerge and take shape. My research seeks to reveal approaches with potential applicability to the assessment of such processes.

Approaches to Performance Assessment

There are at present essentially three approaches to performance assessment used with students in the context of school science: process skills, rotating stations, and extended investigations. A process skills approach treats science investigation as being composed of an hierarchical set of discrete skills and competencies (American Association for the Advancement of Science, 1967; Kuhn et al., 1988; Carey, 1989). These skills are viewed as being mutually independent and it is often the case that activities are constructed which purport to assess one specific skill such as measuring, observing, or hypothesizing. Quite often the activities in this approach are really only paper and pencil tasks involving no manipulative component. In the context of this study, I do not consider these sorts of tasks to be performance assessment tasks.

Process skill tasks which do include an action component are often present in rotating stations sets of tasks. The British Columbia assessment (Erickson at al, 1991) is a case in point. The rotating stations approach is characterized by an array of about 6-8 stations with a specific time allocation (usually 8-10 minutes) assigned for the completion of each task. Students may be engaged individually (Alberta Education, 1995) or they may work in pairs (Erickson et al., 1991). It is usually the case that only the required amount of equipment is provided for the student to successfully complete the task according to a pre-defined strategy. Results are recorded on a response sheet by the student which is then analyzed according to a preset hierarchy of skills. There is usually some effort to construct tasks which broadly reflect the content areas of the curriculum. In addition the British Columbia science assessment includes two extended investigations. One of these tasks, the Paper Towels investigation, is used in my research.

Performance assessment also occurs in contexts outside of school. For instance, students receive feedback about the effectiveness of their activity when they participate in science fair and science olympiad events which are usually conducted outside of a science classroom. A substantive difference between these two forms of assessment is that science fairs tend to encourage students to engage in self-directed activity while science olympiads tend to encourage thinking in a collaborative environment. In addition, whereas science fairs provide students with essentially unlimited time to complete an investigation, science olympiads tend to limit the amount of time available for an activity to occur. The nature of the other tasks (i.e. Ice Cube, Solar House, Invent a Machine, and Mousetrap Car activities) which are part of my study display similarities to both science fair and science olympiad activities. They are similar to science olympiad events in that they are mostly (with the exception of the Mousetrap Car activity) situated within a socially dynamic building environment and they are similar to science fair activities in the sense that they provide more time than is usually available in science olympiad events.

Validity Issues Related to Performance Assessment

An important starting point in the design of any assessment strategy involves construct validity. What is it that is described and/or measured?

In order to establish complementary roles for conventional (i.e., paper and pencil) and alternative (i.e., performance assessment) approaches, Linn, Baker, and Dunbar (1991) present the following validity criteria: (1) consequences: intended and unintended effects on the ways teachers and students spend their time and think about what they are doing; (2) fairness; (3) transfer and generalizability; (4) cognitive complexity; (5) content quality and coverage; (6) meaningfulness; and (7) cost and efficiency.

Two important components of the construct validity of a performance assessment are validity of the interpretation of the assessment and validity of the impact of an assessment on the educational system (Moss, 1992). This is a recent distinction made in response to concerns about the purposes for which performance assessment data are used. Moss (1992) states that

> In the context of educational measurement, attention to social consequences has burgeoned with growing concerns and expectations about the influence of assessment on the curriculum. In fact, many of the arguments raging today about externally imposed versus classroom-

> generated assessments or about multiple-choice versus performance assessments are warranted, not in terms of technical validity considerations, but in terms of the consequences for instruction and learning and for equity (p. 236).

Several sets of validity criteria have been proposed for the above concern with the consequences of testing. Fredericksen and Collins (1989) emphasize a systems approach to performance assessment. They consider a systematically valid test to be one that induces changes in the educational system that are consistent with what the test measures (i.e., the test is regarded as an agent of change). The Assessment of Performance Unit (APU) is a case in point.

Haertel (1991) proposes a set of design strategies to enhance the validity of judgment-based performance assessments. In a judgment-based performance the data are collected by an observer as the task is carried out. This differs from the cases above where student responses are collected and rated.

Performance assessment tasks need to provide the opportunity for students to engage in scientific behaviors. This means that the task should have enough diversity that a student will be able to include aspects of herself into the task and consider the task as an opportunity to design and explore questions and phenomena as they emerge for the student. As long as a task accomplishes this, then the question of whether or not it is a "scientific" task is irrelevant. In my research I have selected a variety of instances of students engaged in tasks at different grade levels, learning contexts and curriculum areas.

Holistic Aspects Inherent in Performance Assessment Activities

How should performance be assessed? What basic assumptions about performance in a science classroom setting are educationally valid? Questions such as this suggest a need to consider the holistic aspects inherent in performance assessment activities. For instance, one can consider the overall quality of an entire performance and assign either a qualitative or quantitative judgment to it (i.e., satisfactory, unsatisfactory, pass/fail, etc.).

In a holistic approach to performance assessment it is not enough for the person performing the assessment to act as an external observer and judge. Student performance can be considered at different levels of inclusion with respect to the sequence of action-thought which emerges during an activity. Holistic assessment requires that the person(s) assessing practical work be at least present for the whole time that the action-thought progressions develop. It is not good enough to observe, interpret, and portray only the products of practical work. Such approaches are better described as assessments of the outcomes of performance rather than performance assessment. Unfortunately, it is this sort of approach which is currently being considered for use in Alberta schools.

Holistic assessment needs to, in some way, allow the persons assessing, the persons being assessed, and any other "reader" of the assessment to participate in the interpretive process. In other words, students and teachers/researchers need be able to contribute to the interpretation of practical work if the purposes of the assessment is to have meaning for them. A holistic assessment needs to be vivid enough that a reader of the assessment can develop her/his own meanings for the action-thought described and interpreted by the author of the interpretive portrayal. In short, the reader must be able to enact a plausible story in reading a portrayal. This kind of holistic portrayal can most plausibly be constructed by an author who is implicated as a participant in the development of action-thought in a practical setting.

Students and teachers/researchers are actors in the practical action-settings and each has multiple interpretations for the action-thought which emerges. Students' verbal and physical dialogue with themselves, the setting, and the teacher-researcher and the artifacts and products (i.e.. written work, sketches, working models) they construct in their practical work can be viewed as multiple perspectives which contribute to the development of holistic portrayals and interpretations of portrayals. Teachers/researchers contribute their own actions and multiple perspectives to a holistic interpretive portrayal. The point is that holistic portrayal not only requires multiple perspectives, it also requires multiple levels of engagement by both students and teacher/researchers.

In considering extended investigations, the broadest and most holistic consideration possible would be to consider an entire collection of investigations or action-thought progressions, successful and unsuccessful, as a whole unit. The response of the BC science assessment was to consider sub-units (i.e., short sequences of investigative activity where one approach was apparently being used) holistically by selecting a single "best" investigation and assigning a subjective overall quality rating. Alberta Education considers each station task as an independent unit and subdivides performance on a task into levels of competency (Alberta Education, 1995).

A second issue concerns the question of whether or not there exists a single correct investigative pathway that students should follow when they proceed through a task. Carey (1989) proposes a scheme for scoring extended investigations that is based on the assumption that there is an optimal or ideal way of carrying out an investigation. Carey's scheme has an hierarchical structure in that it divides the overall experimental process into components to which scores are assigned. These are then aggregated into an overall composite score.

It appears that the question of what holistic assessment is, or at what level it should be used, is not well understood. The validity of an assessment strategy seems to depend not only on the validity of the interpretation but also on the purposes that it serves (Moss, 1992). What purposes do educators have for assessing students practical work and what purposes do they consider it to have for themselves? White and Gunstone (1991) argue that assessment is also a learning activity for students. If we are to properly address the validity issues surrounding practical assessment in science, then we need to develop a better picture of how students engage in action and what meanings they develop for it.

Questions regarding the use of performance assessment as a research tool are just beginning to emerge. My own experience and that of others suggests that there are several important issues which need further examination. For instance, consider the case of the pre-service elementary teachers who engaged in a science project as part of a class I taught. What sorts of things did these people learn in doing this activity?

Other questions involving performance assessment emerge when one considers the area of the transfer of meaning and understanding across contexts. What meanings and understandings do students transfer when they move from one practical science activity to another? Woolnough (1991) claims that the most fundamental competency that students acquire in practical science activities is an emerging sense of confidence and competency in their ability to take subsequent effective action. Woolnough transforms the well known phrase **I do and I understand** into **I do - and I know that I can do more**. Such an enactivist claim, if valid, is a very powerful and motivating mind set for students to adopt in the course of the doing of their science activities. Its implications are explored in the current study.

The development of good performance assessment can be a time consuming and expensive process. It is not only the developing and field testing of appropriate tasks which makes performance assessment difficult, but designing, assembling, producing and distributing of the wide array of equipment also introduces added difficulty and cost. It is one thing to encourage teachers to include performance assessment as a component of their teaching strategy, but it is another to expect them to carry this out regularly in real classroom environments. Much more work needs to be done in developing a theoretical basis for the design and implementation of assessment techniques of practical activity in classroom environments and in documenting how students engage in such tasks.

It is an open question, in my opinion, whether or not performance assessment as it is currently conceived adds a new dimension to science education. I think that many educators would agree that including a practical action component in science teaching and learning is fundamental to the development of understanding. But what does engaging students in such tasks reveal?

Chapter 4: The Design

> *The act of representation also provides the occasion for discovery ... Ultimately, however, representation must give way to the primacy of experience. In the end, it is the qualities we experience that provide the content through which meaning is secured. (Eisner, 1988, p. 16).*

> *Turning the text into a display and interaction among perspectives and presenting material rich enough to bear re-analysis in different ways bring the reader into the analysis via a dispersive impulse which fragments univocal authority. Such writing works against the tendency to become the locus of authority ... (Lather, 1991, p. 91).*

In this chapter I will describe the nature and criteria for the selection of the research settings which yield the data base for my studies of the development of understanding. These settings are naturalistic and are selected according to how well they lend themselves to my evolving research approach. I will describe my research approach as it has developed over a series of studies, my data gathering methods, and some of the materials and engagements that I have introduced into these settings.

I will consider the possibilities, limitations, and assumptions underlying my choice of the events selected to be documented and interpreted in the data portrayals. I will also discuss validity issues and ethical considerations surrounding my research approach.

The Research Settings

The research settings comprise a range of individual, group and classroom engagements over various spans of time. These engagements are either extensive in time, intensive in the level of engagement, or both.

I have worked with one pair of students at various times over a period of three years in a number of research episodes. The first research episode involved a study using the **Paper Towels** task (Shavelson and Baxter, 1992) which was used in the BC assessment. The second engagement designated the **Solar House** project occurred during a four month research engagement with their grade nine science classroom. This was followed by a one month engagement described as the **Mousetrap Car** project in their grade ten science class. One component of the grade ten engagement involved an interview at the home of one of the students (who I will later refer to as Dan) in the pair as they worked on designing and building a mousetrap powered car. A second, summative interview was conducted with one of the students (Dan) after he had completed his high school physics courses 18 months later. A fourth project named the **Invent a Machine** project was conducted in two grade eight science classes taught by the same teacher who participated in the Solar House project.

The four month Solar House project in a grade nine classroom provided many opportunities to engage all the students in their class. My role in this classroom evolved from that of an observer to that of a full participant in daily activities. I interacted with all the students in this classroom during the period of this study and at no time did I select individuals to become standouts among the group. My daily agenda was to allow the setting to unfold in whatever way it would and to engage those students who decided to include me in their work on a particular day. If a student appeared indifferent toward an engagement on a particular day I simply looked for other opportunities to observe or participate. As noted previously, my unit of analysis is persons-acting-in-setting (Lave, 1985). This includes me as well as the students and teacher in a variety of complex enactions and interactions. Part of my analysis involves a construction and interpretation of various meaning making episodes from multiple perspectives.

During this research students engaged in several activities involving two different units from the grade nine curriculum. Two student activities were more extended in nature and emerged from their study of a unit on heat. One involved students in constructing a device for the purpose of minimizing the melting of an ice cube over a period of time. The second activity involved students in designing, constructing, and testing a device similar to a solar house. I looked for instances of self-direction, co-emergence, and embodied action-thought throughout these activities. Various forms of communication, including day to day discourse, an interpretive midpoint written account, and a culminating interview were used to explore the teachers perspective.

I returned to the same teacher's classroom at her invitation in the subsequent year and worked with her two grade eight classes as a resource person while we engaged in a self-directed building project. The Invent a Machine project involved the design, building, and testing of a composite machine incorporating three simple machines. I was involved in the classes on a daily basis over a one month period of time. In addition to the ongoing conversations and consultations, I interviewed the teacher about eighteen months later in order to explore the longer term influence of such activity on her pedagogic practice.

In the course of my research in the Invent a Machine project I learned that the two students from the grade nine Solar House project one year earlier who were also the subjects for the Paper Towels task were students in a grade ten science class taught by a teacher with whom I was planning to work. This provided a twofold opportunity: (1) to continue my interactions with the two boys for a third year, and (2) to observe a building project in a new setting. While it was not possible for me to participate in the Mousetrap Car project class on a daily basis, I attended the class on several occasions before the project began, throughout the time that the project was carried out, and then again on a more sporadic basis until the culmination of the project. Since the project extended over a Christmas break (during which students worked on their projects), I was able to interview two of the students (Dan and Tristen) at Dan's home as they developed their car. I was also invited to the home of one of the other students in this class to conduct an interview that focused on the out of school building activities of his group. Other members of this group prepared a video of their activity as they worked on their car during the Christmas break.

Eighteen months later I interviewed Dan who had by this time completed his grade 11 and grade 12 high school physics courses. This interview was designed to explore Dan's perceptions of his entire secondary school building experience.

One of the main aims in my study was to locate naturally occurring pedagogic instances and settings which can be interpreted from an enactivist perspective. My purpose was not to enter classroom settings with pre-designed tasks that I construct to provoke specific kinds of student actions, but rather to take advantage of action-oriented learning environments as they emerge naturally, with me as an active participant. While I do not preclude the possibility of introducing ideas, materials or activities into the classroom environment, I do this as a participant in the natural environment, and then only as a consequence of the emergence of student's ideas and requests to incorporate the things to which I have access (and they do not), in order to allow continued exploration of a particular area of interest. I may suggest things for students to try, but I will only do so if the student agrees that it is something (s)he would like to try, and only if we both think it fits into the activity context. This is important because it includes students as active decision makers in their own learning and helps to ensure that settings can evolve naturally. Viewed theoretically, I am thus part of my unit of analysis, the persons-acting-in-setting (Lave, 1988).

Limitations

The following considerations circumscribe the domain of my research in this study.

1. While I recognize that the classroom learning environment is a complex social system I will focus my attention on action-thought as displayed in acting moments involving both language and physical action.

2. Since my unit of analysis is persons-acting-in-setting, the basis of my portrayals will be the action settings which inform enactivist ideas and not a selection based on individuals. There will be no attempt to describe the projects or actions of all class members in any given project or engagement.

3. The settings selected for study are middle school classrooms (i.e., grades eight to ten). The main reason is that the settings provided by these grades offer:

   a) a strong emphasis on activity-oriented science,
   b) students who are generally experienced in building and using their hands,
   c) teachers who are flexible in the amount of time spent on activities, and
   d) a curriculum which has opportunities for open, self-directed exploration.

4. My study focuses on activities which are related most directly to the area of the physical sciences. The main reason is that this is an area in which I have experience and a certain amount of expertise.

5. Even though there is variety in the time spans that are described in my portrayals, these are relatively short (a series of classroom periods or weeks). By and large they are culminating activities in units of science learning. The nature of understanding as it emerges in action at other stages in the curriculum units has not been explored. I have attempted to counteract this limitation by revisiting both a student group and the cooperating teacher's classroom over more than one project activity in my research.

6. Except in settings where the teacher's statements and actions have a direct bearing on student actions-thought, the teacher's interpretations of classroom actions and events will not be a direct focus of my attention. I do, however, recognize that the shared and personal histories of the teacher and students in a classroom are an important influence on

what I observe and the nature of my engagements with students. The teacher in the Solar House and Invent a Machine projects was interviewed on two occasions.

I recognize the inherent limitations imposed by my data gathering methods - namely (a) the video camera which is directed toward someone or something, (b) verbal discourse with its multiple meanings and interpretations, (c) observation as incorporating frames of reference of the observers, and (d) written work and drawings produced in an assessment context of which I am not a part.

Assumptions

There are assumptions which are embedded within the theoretical and methodological positions I have adopted in this study and which have been outlined in Chapters 1-3.

My research starts from a position that meaning and understanding are embodied and enacted. I am assuming that students are capable of demonstrating the meanings and understandings they develop through actions as well as language. Furthermore I assume that I will be able to identify, interpret and portray action situations in which meaning and understanding develop. .

A second assumption is implicit in the methodology and how it is used. My research assumes that a researcher holding a video camera and working in close proximity to students and among students can simultaneously record and participate in sequences of student action-thought. The same assumption holds for the use of an audio-tape machine worn by me. This is problematic, and was partially overcome by the presence of my supervisor in the classroom to videotape classroom events, while I worked closely with individual students and groups.

Other assumptions are embedded in the processes of selecting and interpreting sequences of action-thought during classroom engagements. I will identify and interpret student actions and words as they engage in practical work in classrooms in order to portray aspects of the meaning making processes involved. All interpretations and portrayals of a student's (or group of students') action-thought progressions will be done by me after I have participated with them. I am assuming that my interpretations and portrayals of their action-thought processes will be recognizable to the students, or to other researchers/teachers as being potentially plausible, and/or to have verisimilitude (Bruner, 1986).

Enacting Understandings of Classroom Research by Doing

When I first encountered the ideas surrounding enactivism and began thinking about an enactive approach to cognition, my focus was primarily on how it might be used as a theoretical framework for the **interpretation** of sequences of action-thought. The idea that thinking could be considered as being embodied in physical action resonated with my own intuitive sense of the importance of physical involvement in the development of understanding in scientific activity. The idea that thinking can be viewed as a phenomenon involving a dynamic recursive relationship which unifies subject and object, or figure and ground, in coemergent and coevolutionary processes, adds a level of complexity which has typically been absent in previous research interpretative approaches. I continue to be excited about these ideas, and intend to continue to explore how enactivism might provide a theoretical framework for interpreting student action-thought.

During my classroom research engagements over the past two years, a second set of implications for my research has emerged from my explorations of the ideas surrounding enactivism. These implications concern the **nature of my classroom research engagements,** and are the implications which may emerge for the processes of construction of data, interpretation of data and the evaluation of each process. I began to ask questions about how enactivist ideas could be used to inform some of the methodological issues surrounding my research engagements.

I consider enactivism and constructivism to have many similarities in both theoretical and methodological domains. Both perspectives view individuals to be actively involved in the construction of knowledge. Both perspectives consider direct engagements between researcher and student in meaningful settings to be critical to research which attempt to explore the complexities of classroom meaning making processes. Enactivism, however, seems to allow new questions of how knowledge could be constructed to be addressed.

My thinking about a research approach in a high-activity science classroom context has been provoked by the ideas which have emerged from my discussions with my colleagues about enactivism and its implications for research into cognition and learning.

Enactivist ideas have opened up new possibilities for my colleagues and I in considering the roles of the researcher and student as active meaning makers in a learning/teaching setting.

Let me begin by making a comparison between how constructivist and enactivist approaches view the student acting in a setting. This extends, in the context of research design, the comparison began in Chapter 2 on pp. 39-46. A constructivist approach tends to view the actions of students in isolation to the actions of the researcher. Furthermore, students actions and language are usually viewed as "revealing" aspects of their knowledge or thinking. An enactivist approach tends to view the actions of students and researchers as an embodied whole. The research engagement is viewed not only as a process where one side reveals aspects of their thinking to the other but also as a process where each participant (researcher and student) contributes to the creation of new thinking. Such a research engagement is a process of creation and revelation in which both the student and researcher are implicated.

The difference in views just described has a profound impact on how a researcher tends to consider his/her involvement and the implications surrounding his/her participation in a research setting.

A constructivist researcher typically places great emphasis on setting the stage, constructing the background, and providing the context for student action. This allows the researcher to focus her/his attention on recording and interpreting student action and language during a research engagement. The constructivist researcher tends to consider her/his own impact on the actions of students in a research setting as something which ought to be controlled, structured or even minimized. Students and researcher have very distinct roles in the research setting. The student is expected to engage the setting provided, and the researcher is expected to observe and record the student as they act in the setting.

An enactivist research engagement shifts the emphasis away from providing a student with a predetermined context for action toward allowing students to provide their own contexts for action. An enactivist researcher may construct elaborate and carefully designed research settings and/or activities in which the students engage or (s)he may not, relying on a natural setting for the engagement to occur. The commitment toward the constructed or the natural setting is much different than it is in a constructivist approach.

An enactivist researcher is prepared to allow students to abandon or change significantly a context, if that is something which emerges during the engagement. In fact, an enactivist researcher needs to encourage this kind of emergence because it is a good indicator that students are fully implicated in developing meaning through action-thought.

This is a significant difference. A constructivist approach tends to view context as a static component in a research setting. For instance, constructivist approaches which use concept mapping as an instrument for exploring student knowledge building typically apply a two stage design in their research engagements. Students spend a period of time in order to become competent with concept mapping and then data gathering begins in a fairly stable context. Data which might be collected during the first part are not considered useful because the context of the setting is judged to be too unstable. This may be a consequence of a research agenda which focuses more on **what** students know rather than on **how** they develop knowledge (Solomon, 1994).

What may appear to be "common" settings for the various participants may be viewed in different ways depending on whose perspective is considered. Students and/or researcher may view a setting to be relatively stable on some occasions and relatively unstable at other times. My agenda as an enactivist researcher is to become implicated in the unfolding development of meanings and understandings in a learning and research setting by contributing to the action-thought as a participant and an observer. This has allowed me to develop vignettes which portray action-thought from various perspectives and levels of engagement in high activity science classrooms.

There are a number of different perspectives from which I intend to engage and reflect about ways of making meaning in my research. For instance, in the Invent a Machine project, building my own machines helped me to think about some of the complexities involved in the activity and to engage students in conversations about building. It is not surprising that my credibility with students is enhanced when I can make reference to personal experience in discussions about their building. My experience is that students seem to offer more reflections of their own action-thought when they engage with me in thinking about my action-thought in similar activity.

I act as a participant with students in the dynamic action-settings they create. This allows me to observe and talk with students, or engage in silent action with them as they work.

These engagements may be as short as a couple of minutes to as long as an entire class period (40-80 minutes), depending on the arrangement of consecutive class periods. Entering or withdrawing from students' workspaces is not problematic in a high-activity building environment. All my engagements with students during the high-activity building phase of my research are informal. My focus is on looking for opportunities and invitations to participate with students in order to help them accomplish success as it is defined in their own terms. This enhances the quality of the more extended conversations I will have with students as they finish their building engagements and enter a reflective period, where they analyze or test the products of their building. It also enhances my ability to put into context and interpret what students say during interviews with me.

Thus I consider an enactivism to be (1) a methodological perspective which can help a researcher engage in actions which are meaningful and beneficial to all the members of a research setting, and (2) a recursive interpretive perspective which helps to create, interpret, and portray action-thought. An enactivist research approach therefore embodies interpretation within action and action within interpretation. It is both generative and regenerative. It provokes the researcher to recursively surge forward in order to join as an interpretive participant in action-thought as it emerges within a cognitive environment, and to withdraw backward as an interpretive observer of action-thought as in unfolds. The researcher is always a part of the research setting, but at a variety of different levels of engagement. The levels of a researcher's engagement may change very quickly depending on students, context and researcher.

Why study student action-thought in settings where building and physical movement are central? This question needs to be addressed from both a research and a pedagogical perspective. These two perspectives are not independent. I believe that the value of research in science education can be assessed according to the degree to which it informs the practice of science education. It is with this in mind that I designed my study.

Its fundamental purpose is to identify, interpret, and portray features of how action-thought progressions which are naturally developed and spontaneously used by students contribute to the development of understandings which they consider useful to their learning in science classrooms. A fundamental assumption is that students are capable of developing and using their own multiple approaches to develop understanding. A second assumption is that students are capable of revealing aspects of the various action-thought trajectories they use to a researcher. Both of these assumptions presuppose the existence of appropriate contexts within which these events can occur. I suggest that there exists a large number of contexts within which the events of the first assumption can occur and a smaller, yet overlapping, set of contexts in which the events of the second assumption can occur.

Building is generally distributed over a large enough space that it can be observed and recorded more easily than other things such as writing or drawing on paper. It is usually possible for a researcher to record both students and their evolving setting together with a video recorder. Building activity offers the researcher possibilities for participation that are not always available with other kinds of activities. It is usually rather easy to engage, disengage, and re-engage a learning situation. Building generates a physical artifact which can be talked about in a conversation between a researcher and students - not only what has been done, but also how it was done and why it was done. Building has an intrinsic openness and is naturally self-directed. It is naturalistic, is not contrived, and has immediate curricular relevance.

Building is not codified. It is not the only kind of action thought in which students engage in science classrooms, but it is a good place to start in attempting to understand and critique the development of student meaning from an enactivist perspective. Building is a complex activity as is the development of understanding. A more contrived situation may appear to be simpler but it leads into more complex situation for understanding. Building allows one to include a pedagogical component into research. It allows the classroom teacher to participate fully with me and the students toward a common goal.

The Researcher as Teacher in an Enactivist Approach

Cobb and Steffe (1983) argue that the researcher who wishes to explore students' thinking must act as a teacher during the research engagements. They make three claims in order to support their position. Their first claim is that "knowledge gained through theoretical analysis can at best intersect only part of the knowledge gained through experiencing the dynamics of the child doing (p. 83)." Second, they argue that students' interactions with a researcher-teacher are a necessary part of their learning, and allow the researcher-teacher to experience and portray critical moments in the development of meaning and understanding in a teaching context, which has the potential to inform practice. Third, Cobb and Steffe argue that the interaction of student and teacher enhances a research context and students' opportunities to be creative in multiple contexts, in the sense that it provides students with contexts in which they act alone, with a researcher-teacher, and as a member of an entire classroom community.

I tend to agree with Cobb and Steffe's arguments. Their first argument is a theoretical one and is in accordance with the enactivist position I have adopted in my research. As Polanyi (1958) has pointed out several years ago that we know more than we can tell or as Eisner (1988) has restated more recently "knowledge need not - and I would say should not - be restricted to what one can claim. (p. 16)." Their second and third arguments are mostly methodological and make essentially the same claim as I have from an enactivist perspective.

Cobb and Steffe's (1983) argument provokes researchers to consider how to engage students as much as it does how to interpret their engagements with students. I agree with this position. However, I do not agree that the only way a researcher can participate with students, in a way that is meaningful to both the students and the researcher, is by assuming the role of the classroom teacher. For instance in my research, I have not been and will not be responsible for the evaluation of student work. There are good ethical and methodological reasons for this. Ethical reasons involve responsibilities toward students, their teacher, and a respect for the multiple individual and group relationships which exist in a classroom. I may not leave a setting unchanged but I have a responsibility to leave a classroom as a viable entity. Methodological reasons involve the idea that people reconstruct their stories depending on the reader. When students talk to a teacher about their work they usually talk about where they think they might end up and how the outcome of their efforts will be judged. When they talk to a co-participant, they tend to focus more on **how** to achieve a particular goal. The conversation is situated around the many events which are occurring or are about to occur in a work setting rather than about the outcome of those events. A teacher may observe or be aware of the ongoing evolution of a student's work but does not usually become personally involved in the development of a project. A co-participant, on the other hand, is actively involved in events as they unfold. While teacher and a researcher are both actively involved in students' work they may participate in different ways. I will explore this issue further in Chapter 8.

Salomon (1992) has emphasized the importance of studying whole classroom learning environments in conjunction with the individuals within them, in order to understand learning in innovative settings. In my classroom research I engage and participate with all members of the classroom, without consideration of their status as members of the research project in progress. In this sense, I assume a role that is similar to that of a teacher. I consider this to be important for three practical reasons, based on my experience in high activity science classroom settings. First, many students seem to be aware of, and consider important, the researcher's engagements with members of the class at multiple levels. In other words, many students notice and place importance on how the researcher engages the entire class and other subgroups within the class as well as with themselves. In fact, a researcher's relationship with individual students, and the opportunity to participate with them in the development of action-thought, may depend as much on how the researcher engages other students and/or the entire class, as it does on how the researcher engages that particular student. This is an intriguing methodological assertion which could potentially have consequences for how cognitive research is conducted and is something I intend to explore in my further research.

How Does an Enactivist Perspective Consider the Curriculum?

Eisner (1988) has referred to the curriculum as a mind altering device.

> What we teach, whether in the primary school or in the university, is a means for altering the ways in which students think. Our programs are designed to have such effects and, when they fail to change our students' ways of thinking, we regard ourselves as having failed. It is in this sense that education is an enterprise fully political in nature. (Eisner, 1988, p. 19).

The curricular aim of self-directed engagement is not primarily to alter the thinking of students. Rather, it is to allow students **opportunities to experience and develop their own ways of thinking** and develop meanings from these experiences. Conceptual change alone is no longer the bench mark for success or failure. What then becomes a bench mark for success? I believe it should be the primacy of the students' experiences as revealed by the degree to which she/he can enact it. For example, we cannot judge the success of such a curriculum for students if we base it only on the outcome of the stories they provide for us in forms we have chosen for them. Rather, we should base it upon the vividness and richness which emerges from students' enactions of their own stories, for themselves and for us, in whatever forms they choose to enact them. These are important aspects of an enactivist curriculum agenda.

Phenomenographic Description

How do students conceptualize scientific phenomena? How do researchers make sense of how students conceptualize scientific phenomena? As researchers we are constantly concerned with answering two fundamental questions; (1) What do I know?, and (2) How do I know it? (Fensham, 1993).

In pursuing these questions two separate research agendas have arisen. The first, to which I refer in general as the constructivist approach (Pfundt and Duit, 1991), has been motivated by conceptual difficulties which have arisen in the teaching of science to students. This research agenda has been grounded in a curriculum agenda in the sense that the probing situations generally have their origins in the content of the scientific curricula. Thousands of studies (Pfundt and Duit, 1994), done in many countries over the past seventeen years have described the structure of students' conceptions of various phenomena. This has had a positive effect on the international science education teaching and research communities in that it has brought them together (to a degree). However, a concern has arisen in the research community that too much effort has perhaps been spent at the descriptive level of constructivist research, and not enough effort has been given to developing a deeper understanding of how conceptions are related to each other or to how they can be changed.

In Chapter 2 and on pp. 66-67 of this chapter, I have drawn some contrasts between constructivism and enactivism as theoretical positions and ways of conducting research. A third perspective relevant to my research approach resides in an investigative stance known as phenomenography (Marton, 1981). It was briefly referred to on page 19, but now I insert a section here which compares and contrasts aspects of phenomenographic inquiry with that of the more widely known constructivism.

The phenomenographic approach has been used (Renstrom et al., 1990; Dall'Alba et al., 1989; Linder and Erickson, 1989) in an attempt to develop a deeper understanding of student conceptions of scientific phenomena and as a potential bridge toward knowledge of how student conceptions can be changed through science instruction. In viewing students' conceptions differently from how they are viewed in the constructivist research methodologies, phenomenography has shifted concern toward issues which have been relatively unproblematic to this point.

Both research agendas largely assume that students reveal "what they know" as a response to some well-chosen probing methodology. The student is presented with a situation which elicits responses, which are then interpreted by the researcher according to some guiding assumptions. This can be done either by focusing on the student as the unit of analysis or on the set of responses given by students as the unit of analysis. Constructivist researchers tend to follow a relatively straightforward approach in trying to accomplish this task. In addition, they typically ignore the question of **how** students know what they know.

The responses may take the form of verbal discourse, written responses, drawings, or physical action. In other words, what a student says or does reveals something about how they think about the world and about their thinking. Phenomenography also accepts this premise, but presents an alternative research agenda in developing it.

In pursuing an aim in this section of examining the phenomenographic approach to the study of student thinking about scientific phenomena, I am comparing and contrasting it with that taken by the more widely used "alternative conceptions" approach of constructivists. While variations exist in how science conceptions are viewed in this approach (e.g., childrens' science, misconceptions, alternative conceptions, preconceptions, spontaneous reasoning), I will deal with the constructivist research approaches as a combined entity, except when specific distinctions are helpful in illustrating a contrast with phenomenography. My analysis will focus on underlying assumptions and, to this end, I discuss issues and questions which contrast the use of phenomenography as a research methodology with constructivist approaches. In this discussion, I intend that the influences of phenomenography on my own specific research agenda will become clear and be acknowledged. The aspects of phenomenography which are consistent with or have stimulated my enactivist thinking are underlined.

1. Learning in relation to our experiences.

The constructivist approach assumes that students construct new knowledge based on their interactions with their environment. Phenomenographers accept the role of these interactions, but differentiate the process of knowing that occurs. The constructivist perspective describes learning as an outcome of a process which involves reorganizing old conceptions or constructing new conceptions of the world. The phenomenographic perspective asserts that people learn through new ways of experiencing the world. Thus, although both perspectives, embrace interaction and experience for learning each chooses a different emphasis on how knowledge develops from them. Constructivist research tends to focus on the outcomes of a process of knowledge construction while phenomenography attempts to focus on knowledge aspects of the process itself.

2. Students views are revealed by what they say and do.

This is a necessary assumption in the sense that, if we do not accept it, then it would seem that there is not much point in proceeding any further with the research agenda of trying to understand aspects of student thinking. However, this assumption remains problematic. Students cannot tell us directly about certain tacit dimensions of their thinking but these seem to be fundamental to the development of understanding (Polanyi, 1983).

While it seems likely that there will always be some aspect of student's knowledge and thinking that research will not be able to describe, the body of work which has been compiled about students' conceptions is compelling, in the sense that it seems to many teachers and researchers that it does describe important components of students conceptions of scientific phenomena. An important concern, however, is that both these current research methodologies have tended to focus analysis more on what students say (i.e., interview discourse) than on what they do. Furthermore, both methodologies which have considered what students do have tended to analyze only the products of student's engagement with the tasks (i.e., pictures, diagrams, or verbal accounts) and ignore the actions of students in their engagement in the tasks.

How might a student's thinking and understanding develop if they are given the opportunity to choose how they will enter or exit a task? For instance, a student who chooses to engage a task setting without instruction may not only have a different experience, the progression of his/her thinking may be quite different. How a student acts to engage a subsequent task setting or to re-enter the same task setting after exiting it may be as rich a source for research interpretation about the nature and development of that student's thinking as the linguistic data a follow-up interview might provide.

3. Short term (typically 40 minutes) "snapshot engagements" with students engaged in structured tasks reveal aspects of their natural thinking.

Both the constructivist and phenomenographic approaches gather data by engaging students in activities, but invariably, in short ones. This is problematic in the sense that a more longitudinal approach would have to somehow account for changes in student learning and accommodation which could be very difficult. The usual arguments in these two agendas supporting the short engagement approach rest in the stated purpose of revealing meanings the student has already constructed or acquired, respectively.

4. The researcher controls the research agenda.

Who controls the evolution of action and language in a research setting? Both constructivist and phenomenographic approaches place responsibility on the researcher to initiate action or discussion, usually verbally, and ask the student to respond to such initiatives. In this sense, the researcher controls the agenda for action and discourse in both research approaches.

If a researcher controls the progression of an engagement with a student then to what degree will that student act and think naturally? This is even more problematic in a clinical setting such as those used by Piagetian constructivists (Pines et al., 1978; Posner and Gertzog, 1982), because to a degree the researcher must control the agenda of what the student sees and does. It may be that both approaches could gather a richer data set if there was a more active attempt to allow students the opportunity to make their own decisions about what to do, what not to do, and how to do it.

5. Where do conceptions "reside"?

The constructivist approach generally considers conceptions to reside within the individual. However, some branches of constructivism deal with the question differently. Radical constructivism (von Glasersfeld, 1984, 1995a, 1995b) considers conceptions and experience of the world to be peculiar to individuals. Social constructivism (Vygotsky, 1978, 1986; Wertsch, 1991; Wertsch and Toma, 1995) asserts that some conceptions are the constructions of a society, and that as such they are shared by the members of that society. One position requires the researcher to focus on individuals as the unit of analysis, while the other suggests that larger connected groups of people form the appropriate unit for analysis.

Phenomenography is fundamentally different in that it considers conceptions to reside in the **interactions** people have with the world around them (Marton, 1981). In phenomenography the world is distinguished according to individual phenomena (i.e., matter, force, heat, growth, light) then each phenomenon is considered to have its own characteristic set of ways in which it can be experienced and thought about by various people. A description of the entire collection of ways a particular phenomenon can be conceptualized by people forms its "outcome space". A phenomenographic approach focuses on a number of individuals' ways for interacting with the world in order to construct a detailed outcome space. It is different from both radical and social constructivist approaches in that it chooses to focus on a set of processes of interaction as a unit of analysis rather than the individual or the group.

6. What are the sources and intentions of the tasks?

The tasks used in constructivist approaches are generally taken from a specific subject area of the school curriculum (i.e., biology, chemistry, physics). Furthermore, the tasks are thought of as activities which could also be appropriate for teaching and Gunstone and White (1991) have suggested that good constructivist research probing techniques should indeed be used as teaching strategies and as formative assessment techniques.

Phenomenography seems to be more ambiguous on this issue. While it may be the case that tasks used in this approach may be taken from a school based context or adapted to be used in classrooms, there does not seem to be an underlying agenda to construct tasks which might be transferred into teaching activities. Whereas many constructivists tend to view tasks as probes, phenomenographers tend to consider tasks as backdrops or contexts for an engagement by the student, and for the researcher.

Both constructivism and phenomenography consider research tasks as opportunities for students to engage phenomena and researchers to engage students. The student is expected to think about phenomena, while the researcher observes, probes, and interprets the student's engagement. Neither perspective considers how this separation of agendas impacts on the evolution of thinking, by either the student or researcher, in the setting. In the sense of these two approaches, building projects involve a chain of phenomena.

7. Validity and Reliability

Issues of reliability and validity can be considered from the point of view of consistency of results. While this has typically not been dealt with in any one study, a large part of the body of research done in specific concept areas e.g., gravity (Gunstone and White, 1981) has shown that similar results have been replicated over large groups of students in different countries, at different times, and in different task contexts. In an indirect way this speaks to the consistency requirements of reliability and validity. The generalizability requirement of validity is addressed by the fact that the ways of meaning revealed by constructivist research have been observed by many teachers in non-research classroom environments.

In the phenomenographic approach the unit of analysis is the conceptions. The conceptions are not localized to individuals and are portrayed in the form of an outcome space. While the constraints surrounding reliability and validity remain the same the issues are dealt with differently in the phenomenographic approach. From the point of view of consistency of results the phenomenographic researcher needs to show that an outcome space for a particular phenomenon is stable over time and context. They argue that stability over time and context can be evaluated empirically with many different studies in the same way as it is done in the constructivist approach. However, this remains to be empirically tested as yet. Phenomenographers argue that their method has the advantage of sampling many contexts with a small number of students because of individual variability. While this may be the case, its advantages have yet to be documented.

8. How is context considered?

The constructivist approach takes the view that conceptions are located within an individual and are stable across contexts. Once a conception is identified for a particular individual it is assumed that the person will hold the same conception in other settings. For instance, if a constructivist researcher finds that a student holds a particular conception in the context of a clinical interview then it is usually assumed that the student will also hold the same conception in a classroom setting. While this may be the case in some instances, it is dangerous to assume it in general.

The phenomenographic approach takes Lave's (1988) view that context is an essential determinant of the way an individual conceptualizes a phenomenon. Once an individual is characterized as thinking about a situation in a particular way it is not assumed that the same conception will appear in another setting. In fact, Renstrom, Andersson, and Marton (1990) have shown that an individual can apparently hold a number of different conceptions of the same phenomenon in different contexts. Presenting contexts are, however, assumed to be stable, and there is no sense of them evolving over the short engagement time.

Validity and Reliability Issues

Flinders and Eisner (1994) describe four dimensions to the structure of critical educational thought: (1) a descriptive component which involves portraying the qualities of our observations; (2) an interpretive component which involves constructing conceptual frameworks to account for our observations; (3) a thematic component which involves generating more general understandings from our particular understandings; and (4) a normative component which involves selecting and describing specific "good" observations which inform the domain of interest. Each of these components is accompanied by inherent validity considerations. While all four are present in my work it is the first three which are emphasized. Articulating the specific validity issues form a part of the analysis in my study. I concur with Lather's (1991) position that data might be better conceived as "material for telling a story" (p. 91) which serves to enhance interpretation rather than as snippets of dialogue intended to support or prove interpretation.

Flinders and Eisner (1994) also identify three criteria for assessing validity in qualitative classroom research: (a) consensual validation; (b) structural corroboration; and (c) referential adequacy. Consensual validation involves sharing aspects of one's research with others knowledgeable in the area. The portrayals I have constructed have been shared with various individuals. For instance, I shared some portrayals with the classroom teacher and selected students and invited their comments. Interactions of this sort were opportunities for continued exploration and development of my portrayals and the interpretations they contain. Structural corroboration deals with the "weight and consistency of cumulative data (p. 354)". This implies that my research portrayals should allow the reader to follow the sequences of events and lines of reasoning which cause me to make specific assertions within or across individual portrayals. Referential adequacy "gauges the degree to which the criticism enables the reader to experience qualities within the situation (p. 354)". Once again this criterion is something that is taken up in the next section on page 82.

Moss (1992) has raised concerns regarding the epistemological assumptions inherent in the application of traditional validity criteria to educational research. She argues that the traditional approach is located within "a social science tradition that stresses theory-based hypothesis testing, attention to behavioral consistencies, and control of factors irrelevant to the intended inference". Questions of power and privilege are implicit in such an approach. If students interpret a research engagement in such a way that they consider the researcher to be "in control" then is it reasonable to expect them to engage in natural action-thought? It may be the case that developing what one considers to be a sufficient understanding of issues of validity and how to deal with them before engaging in a research setting may not be possible or desirable.

Cherryholmes (1988), in arguing that construct validity should be undertaken from a variety of epistemological perspectives states:

> The flow and control of mainstream construct validity discourse conceptualize researchers as subjects, individuals as objects of research. Researcher-theorists regularly impose categories, constructs, statements, modes of argumentation, models, metaphors, literary allusions, descriptions, explanations, and theories on those they study. Research discourse-practices so constituted and reconstituted are designed to generate authoritative knowledge (p. 429).

Generating authoritative knowledge is not the object of my research approach. An essential component of my research engagements and the interpretations that emerge from them is to privilege the actions and interpretations of the students with whom I interact. Privilege is given to students' action-thought and its interpretation through: (1) their engagement in self-directed exploration; (2) active listening and participation by the researcher acting together with students; (3) the researcher being simultaneously attentive to the needs of the classroom community, its small groups, as well as its individuals; and (4) the inclusion of students in the generation and regeneration of interpretive portrayals.

Wolf, Bixby, Glen, and Gardner, (1991) raise the concern that a technically elegant approach to validity issues may distort both the roles of students and researcher in that it excludes them from becoming active participants in the generation of standards for interpreting their action-thought. They argue that an approach aimed toward interpreting action-thought should: (1) abandon the notion that students follow a single progression in gaining and interpreting experience; (2) "revise our notions of high-agreement reliability as a cardinal symptom of a useful and viable approach to scoring student performance" (p. 63) and consider evidence for the development of understanding from a variety of perspectives; (3) develop more holistic ways of looking at student performance; and (4) "consider different units of analysis ... because so much learning occurs either in social situations or in conjunction with tools and resources, we need to consider what performance looks like in those more complex units (p. 64)".

Engaging in research and enacting one's understanding of the issues involved may be the best way to grasp the issues surrounding the validity of an approach. Moss (1992) has suggested that one way to deal with this difficulty is through a recursive approach "in which one inquiring system is observed by another inquiring system in order to probe the methodological and value assumptions underlying each system. (p. 231)". This suggestion appears to be in accordance with a fundamental notion of enactivism, namely that intrinsic recursive connections emerge whenever a cognizing agent attempts to act toward or in response to a subject. However, this is not an epistemological or ontological trap from which we should try to escape or feel compelled to overcome. It is simply a statement of one of the few things of which we can be relatively sure, that a researcher and her/his approach is an intrinsic part of that which (s)he is trying to understand. Acknowledging that validity issues continue to emerge and evolve throughout the course of a study (not just at the beginning) may cause some researchers à certain degree of discomfort. However, as Eisner (1993) muses, "working at the edge of incompetence takes courage (p. 10)".

Data Portrayal

I have constructed data portrayals (vignettes) which aim to describe and interpret the development of a variety of student action-thought progressions based on the multiple engagements and research perspectives which emerged from our classroom interactions. Portrayals of action-thought are based on things students did, said and wrote across various classroom research settings over an extended period of time. For instance, what and how students did or said things, while they engaged in a hands-on invention project are considered in coordination with what they wrote for the teacher or myself and what they said in a follow-up conversation with me in order to present a comprehensive description and interpretation of how they developed meaning and understanding in that project is also included.

I have argued in another section (pp. 71-72) that it is neither possible nor desirable to consider a student in isolation to everyone else in a high-activity action-oriented science classroom. My focus is on action-sequences which involve students and me at various levels in the classroom. For instance, interpretations and portrayals involving students and myself may be constructed from the perspectives of the whole classroom, small groups, or individuals. However, the portrayals I have constructed do attempt to describe the action-thought sequences which emerged from my engagements in a classroom at the multiple levels described above. Thus, it can be said that my portrayals are more about the thought-action sequences which emerged and took shape in various engagements than they are about any individuals or groups of individuals in a classroom.

My portrayals are written in a way that focuses on action-thought sequences specific individuals and myself working together. For instance, a portrayal may be based on experiences I had from a series of interactions involving a particular student in different settings involving different people in the classroom. In other words, in these cases I am assuming that relatively stable and identifiable sequences of action-thought can be identified, interpreted and portrayed across a variety of different settings or in a dynamically changing context. Sequences of engagement between students and myself may range from very short and sporadic to relatively long and continuous in a high-activity science classroom. My portrayals attempt to describe and interpret the emergence and progression of action-thought sequences in as much detail and over as long a period of time as possible. I do not expect that the various portrayals I have constructed include a common timeline, a common context, a common number of students or a common degree of involvement on my part, even though I have attempted to clearly identify these things in each portrayal. What I do expect each portrayal to have in common is that it deals with the development of sequences of action-thought as they emerged in the larger context of an extended classroom project involving self-direction and building.

Any **verbal account is from one perspective and has an implicit narrator**. In this report I am attempting to describe an evolving setting of action-thought from multiple perspectives. One way of doing this is to provide a parallel verbal account from the perspective of the student and from my perspective as a participant in the action (see the two accounts of **Jill's Investigation** presented later in this Chapter). Such accounts, while useful in focusing on the perspectives of the narrator, cannot describe interactions among the two perspectives. Nevertheless, I attempt in a broad schematic way to identify not only the key points of the action-thought of the individuals participating in the setting, but also key points in the mutual engagement and reconstruction of the setting.

In most verbal accounts the narrator is me acting as either an observer or a participant in an action-setting. In other accounts the narrator is me attempting to portray the perspective of the student, that is, I attempt to portray the phenomenology of the student. In yet other accounts I am attempting to portray my own phenomenology as a co-participant with students in a setting. What I have not been able to construct is a portrayal which encompasses all three perspectives simultaneously. One way to attempt to construct this sort of portrayal is by using a schematic depiction. Such a depiction would have the advantage of allowing one to identify points of linkage among the three perspectives. It would also has the advantage of allowing the reader to simultaneously engage at multiple levels and to construct a whole in relation to parts as well as parts in relation to a whole. More than one whole may be constructed from any selection of parts depending on how the reader engages and interprets the portrayal. Metaphorically I am attempting to delineate the difference between a video and a photograph. A video takes a viewer on a pathway of action while a reader uses a photograph to construct their own pathways of action-thought. The levels of the engagement and the possibilities which can emerge are qualitatively different in each case. One way for the reader to assess the viability of such a schematic definition would be to reflect on the independent ideas which emerge for the reader in their engagement with it. As a reader, in the act of engaging a schematic portrayal, begins to perceive herself to be laying down her own interpretive pathways of meaning (as opposed to following ones laid down by the author) then the portrayal becomes more enactivist in nature for everyone.

I intend to continue exploring and developing a style for the writing portrayal of the development of students' action-thought. Once a portrayal has been written I have not considered it to be "written-in-stone". When readers have suggested improvements (additions or deletions) then I have attempted to make changes and consult the person(s) who initiated the change. Ultimately, however, I have been responsible for the writing of the data portrayals I present in this report and I have not expected or encouraged the students to contribute to the writing of vignettes. While it would have been extremely interesting, because it would have constituted a very different source of data for interpretation, students did not have the opportunity to read and reflect on the portrayals I developed about their action-thinking. One of the teachers, Ms. B., was given the opportunity to read and respond to some portrayals and the enactivist themes which emerged from them. Her comments in this regard are presented in Chapter 8.

I have explored other approaches for engaging the students (who are the persons-acting-in-setting) in thinking about their own thinking. One such approach involved replaying video for pairs of students which shows them working and then inviting them to select and discuss segments which they consider to be meaningful for them. There were a number of difficulties in using this approach. The approach was difficult to use with students during high-activity, hands-on classroom engagements. The classroom environment was not appropriate for a video review session with a small group of students because there are too many distractions nearby. I have tried to address this by conducting video review sessions in a separate room near the classroom. While this could work, it removed me from the classroom for a fairly extended period of time and I believed that I ought to be in the classroom continuously during the intensive building phase of a self-directed project for two reasons. First, I had a responsibility to be available to interact with the entire group of students in the classroom while they were building. Removing myself for extended periods of time conflicted with that responsibility. Second, the multiple experiences I had with students during the high activity building phase of their projects was central to my developing understanding of how they develop action-thought, and my participation in that aspect of their work allowed me to interact more effectively during follow-up interviews.

Replaying video "on the spot" with students was probably not necessary in any case. It may well be the case that this was a new experience for students anyway. If this is the case, as I believe it was, then a video review session may just as well be conducted with students at a later time out of the classroom. The question of what such a session revealed about students' developing action-thought is more problematic. If such an experience is viewed as a new experience, then my interpretation of students viewing themselves on video may reveal more about how they think about video than it does about how they developed meaning in action and through the action of building. I intend to keep this video avenue open as potentially useful and intend to continue exploring its use. At best, this approach would contribute one more perspective to the construction of selected vignette portrayals. Since the vignette portrayals have been written from experiences which emerged from several different perspectives, and not all vignettes incorporate the same number of sources, the inclusion of data from this video approach is not central to the portrayals I have constructed.

The collection of portrayals I constructed is highly situated and comprises one of the outcomes of my research. These portrayals have the potential to inform the development of exemplars for the interpretation of action-thought in the assessment of student performance in science classroom settings.

The following vignettes illustrate examples of two of the kinds of action-thought portrayals which I explored as I developed an interpretive approach for my research. The first excerpt describes an attempt by Jill, a ninth grade student, to understand through her actions a question which emerged from a discussion during a previous class about the flow of heat in a convection box (Figure 3).

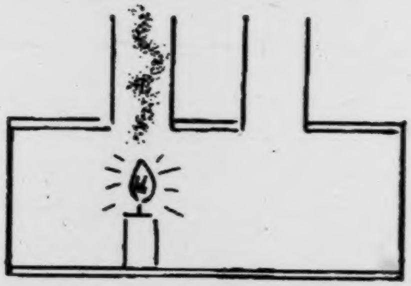


Figure 3: Convection box apparatus

Jill's Investigation

Jill has a question. It involves the convection box she is exploring. Other students have already experienced phenomena arising from this piece of equipment. They have told Jill that when they placed their hands just above (10-15 cm) the chimney a sensation of intense heat was felt immediately whereas it took longer to experience a sensation of similar intensity when the chimney was covered with their hands.

Jill disagrees. She has apparently had the opposite experience. And why not? Heat is more concentrated near it's source (just above the chimney) as opposed to farther away (about 10-15 cm above). Jill resumes her explorations with the convection box while other students work together doing seat work. She lights the candle in the box and puts her hand over the chimney as she had done before. She leaves it there for a little while before crying out, "See it's hotter here (top of chimney) than here (moves her hand 10-15 cm farther up)". Another student joins and tries the same actions. She disagrees with Jill and points out that the heat begins to go out the "cool" chimney when the "hot" chimney is covered. Jill decides an explanation must involve her hand sensing heat differently and talks about the distribution of nerves in her hand.

Jill continues her exploration. First, she observes smoke from the burning "touch paper" going down into the "cool" chimney when both chimneys are left open. Second, she observes the smoke changing direction by going up the "cool" chimney after she blocks the "hot" chimney with her hand. "But that's only telling me where the air is going... heat rises" she announces in frustration.

A couple of other students join her and she explains her dilemma to them. One student suggests that it takes a few seconds for the covering hand (over the chimney) to get hot because the act of covering pushes cool air down into the chimney. He demonstrates this by moving his hand up and down over the chimney a couple of times. Another student joins and says "OK, do it like this" and moves his hand back and forth horizontally over the chimney. "See, I don't push any air this way."

Jill steps back, her gaze focused on the apparatus. She appears to be thinking hard about the other explanations. "But heat rises" she protests. A student suggests tilting the box on edge so that the "cool" chimney is higher than the "hot" chimney to see if smoke will go out the cool chimney even though both chimneys are open. They try it. Smoke goes out the hot chimney as before.

Jill announces that she's still not satisfied with any of the explanations put forward. When asked about the tilted box attempt Jill replies "Oh, that's Cam's idea."

A single explanation emerged from the earlier class discussion. This explanation stated that air, heat, and smoke moved down and into the cool chimney and up and out of the hot chimney when there was no blocking of either chimney. The air, heat, and smoke simply reversed direction and moved out of the cool chimney when the hot chimney was blocked.

In contrast, a diversity of complex and new actions and ideas emerged during Jill's investigation as she explored the phenomenon in a relatively self-directed setting. An explanation that heat moved up one side of the blocked hot chimney and down the other before exiting out the cool chimney seemed to emerge together with the movements of her hand over the hot chimney. She experienced a delayed sensation of heat when she blocked the hot chimney. The idea that a hand pushes cool air into the hot chimney as it is covered evolved in a similar way. An attempt to understand the situation by tilting one end of the convection box so that the cool chimney was higher than the hot chimney emerged from Jill's previous action-thoughts. The variety of pathways of action-thought which students bring forth and explore serves to illustrate the importance of self-directed action and physical contact in activity based science.

Despite numerous trials and conversations Jill never did resolve the situation to her satisfaction. This is not the point. The point is that her understanding of the "problem" evolved in a dynamic way as action-thoughts emerged together with the events of the setting, and that focusing on different aspects of the phenomenon yielded other events, and hence interpretations and understandings of the problem.

Thinking and understanding for a student or teacher in a science classroom is a complex process which is highly contextualized, situated, and occurs on multiple time scales. Maturana and Varela (1987), Searle (1992) and Bateson (1979) suggest that the observer is also an intricate part of a meaning-making process and its context. I illustrate this point by returning to the Jill episode, this time presented from a vantage point which includes me as a participant in the episode.

Jill's investigation revisited

"What are you planning to do Jill ?"

I'm just working on this because I don't understand it ... when you put you hand on top of this (points to the "hot" glass chimney above the candle) ... really close you can't feel anything ... like it's not really warm ... they said that the explanation was because the heat can't get out of there so it goes out the other one ("cool" chimney) ... but the heat is going to rise ... because heat rises ... and it doesn't know that the hand is on top." I sit down nearby and say **"OK, well you go ahead and do what you were going to do. I'll just sit here and watch."**

Jill lights the candle and Karen joins in the activity. I stand nearby and watch quietly as they work. I'm not sure what they are trying to do. Their hands move up and down over the "hot" chimney and they pause briefly to rub the palms of their hands and stare at them intently. Similar actions are repeated several times. There seems to be more complexity to their experiences than just a sensation of heat. **"What was that thing you were trying to understand Jill."**

Jill takes her hands off the convection box and looks up. "OK, well I didn't do this before but when Karen and her group did it they said when they put their hand right there ... right touching it (puts her hand directly above "hot" chimney) ... it was not as hot as when they felt it up here (hand moves about 15 centimeters above the same chimney) and so we started discussing it and the conclusion was that the heat can't travel out the top so it goes out the other one (points to the "cool" chimney), but heat rises and the heat has to get to the top of this chimney (points to the "hot" chimney) before it can go out the other one." My curiosity overwhelms me. I need to experience this phenomenon. **"Can I try it?"**

Karen and Jill look up, surprised by my request. "Yeah" they say in unison and make a space for me to get close to the box. As I put my hand over the "hot" chimney I remember that I want to be careful not to "steamroll" Jill or Karen by my actions. However, I still feel a need to get "in touch" with this phenomenon. I pull my hand away and ask for help. **"Tell me what I need to do."**

Jill acts out instructions with her hand as Karen gives verbal directions. "Well first of all put your hand right there (about 10-15 cm above) and feel how hot it is ... then just kind of go, just put it down to see if it gets hotter ... you don't have to keep it there or anything." I try to understand by doing. I put my hand, palm down, at the upper location and wait. It feels painfully hot almost immediately. I repeat this at the lower location. It takes a few seconds longer before my hand feels the same sensation as before, **"It seems not quite as hot down here. "**

Karen adds complexity. "Yeah, well if you hold it down long enough it will be." Jill doesn't agree. "But I think it's because of your hand" she says. Jill places her hand at the spot where mine had been just before. I am caught up in my own actions and sensations. I want to touch the "hot spots" over the chimney and feeling how long it takes for my hand to get sore. My hand becomes an instrument which feels an answer to my questions directly and immediately. My hand is at the upper position. I decide that the pain in my hand occurs more quickly. I stare at the "hot" chimney and then into the palm of my hand, **"Right here it gets hot ... it seems to get hot a little quicker here."**

Several cycles of action and explanation take place before I get a clearer picture of how Jill has been thinking. Jill considers the movement of smoke to indicate the direction of air movement but not the direction of heat transfer. Jill seems to considers the flow of heat to be independent of the flow of smoke or air. In her opinion, heat can only rise and therefore it can only move out through the "hot" chimney. Explanations suggesting that heat moves out the "cool" chimney when the "hot" one is covered do not make sense to Jill. I can now begin to understand why.

As noted earlier, Eco (1994) uses the metaphor of "a walk in the woods" for a story. One can experience the woods in numerous ways depending upon one's action-thoughts in a setting (e.g. to be traversed quickly, to linger, and the like). Similarly, in classroom research settings, the researcher can choose a variety of ways of participating in the unfolding dynamic. The way which is chosen influences what is salient to the portrayal (i.e. in the meanings which are created). The above excerpt illustrates the construction of knowledge-in-action on the part of the researcher in a way I view as consistent with enactive or situated approaches to meaning-making. In this instance, the researcher's participation in the actions ***under the direction of the student*** is central to coming to understand what the experiences meant to the student. Instead of asking the student what she was thinking I asked for guidance on what to do. I suggest that such questions are useful in revealing ***how*** a student thinks about a phenomenon or, in other words, what meaning it holds for the student.

As mentioned earlier (p. 19), phenomenographers make a distinction between first-order and second-order perspectives. In a second-order perspective focus is shifted from the person's conception of the phenomenon to the ***way*** in which the person thinks about it. The implication of an enactivist perspective to research methodology is that second-order portrayals are an important element in describing the evolution of dynamic understanding.

Ethical Considerations

In accordance with University of Alberta and the Social Sciences and Humanities Research Council (SSHRC) ethical guidelines written informed consent was obtained from all class members to audio and video tape and collect samples of their work where appropriate. It was emphasized to students that, the written consent notwithstanding, they were and continued to be free to decline to participate in any day to day encounters whenever they chose. If I sensed that a particular student or group of students was uncomfortable with my presence, then I turned my attention elsewhere. I noted that students quickly became accustomed to the video-tape, and when interest was expressed they were allowed to manipulate the equipment themselves. Written materials were photocopied from originals submitted by the teacher after they had been collected as assignments.

The domain of ethics also extends to the interpretations which I planned to create. In the Solar House project descriptive accounts of classroom engagements were submitted to the cooperating teacher. The cooperating teacher was also interviewed about the classroom events and interpretations of them. It is in this realm that questions surrounding the validity of interpretation and questions involving the ethics of interpretation intersect. I invited the cooperating teacher to present her reactions to both the nature and the accuracy of the interpretations of the portrayals which I had created. I have presented the teacher with a compilation video of classroom events from the grade nine project. She used this video in her classroom with her students and presented it to their parents in a parent-teacher meeting.

Finding time to interview students in a school setting was and continued to be a problem. I terminated interviews whenever I sensed that students were becoming restless or uncomfortable. This rarely happened but there were times when I was unable to explore issues in as much depth as I would have liked, because I was mindful that students had other commitments. Home visits were made at the invitation of the students involved and their parents, and were conducted in the presence of those parents. All names have been changed in the written portrayals.

Chapter 5: Enacting Understanding

A science project can be anything. That's part of science, you're creating new things. (Tim, grade 8)

This chapter will present instances that illustrate the scope of enactivist ideas as an interpretive framework for descriptions of the development of student understanding. Enactivist ideas can be considered to apply at various levels of description and interpretation ranging from rather direct portrayals of the visible enactment of understanding e.g. a student building a model or structure, to complex dynamic systems where ideas and actions are consensually and recursively negotiated e.g. science classroom discourse. A series of portrayals of action-thought are presented and interpreted from two mutually complementary perspectives: (a) contributions that enactivist ideas make to our understanding of classroom learning, and (b) how the instances of enaction contribute to our development and shaping of enactivist ideas themselves within educational contexts. Enactivist ideas direct attention to certain aspects of the world into significance and the emergence of that significance is in itself a test or validation of the utility of these ideas. Patterns of recursion serve as a framework for both identifying and delineating the events which are portrayed as vignettes.

The embodiment of experience and cognition: Laying down a path in walking

I have chosen a vignette of a car building project that was undertaken as part of the grade eight **Invent a Machine** activity to illustrate a primary or direct level of enaction in which an individual's actions serve as the entry point into a process of understanding. As noted earlier, the-play-plan-act triad can be entered at any of its stages. In school settings students are normally required to plan before they act. This requires the individual to imagine (i.e. to form an image of) the projected outcome of an activity. This projection can either be in the form of a verbal statement such as a goal or purpose or some kind of diagram or sketch. The intended audience of the projected outcome also enters into its construction. To whom is a student speaking when she/he constructs a projected outcome? What purposes does a student consider the construction of a plan for action to serve? Is it intended as a personal guide for developing an understanding of what or how to do something or is it intended for the teacher? Teacher normally require students to prepare a plan, partly in order to be informed about and hence to be able to manage the complex patterns of activity which are expected to develop. Teachers also require students to prepare a plan because it is considered to be good practice in scientific thinking and everyday problem solving. Teachers also expect that the construction of such a plan will help students to successfully into effective action-thought. Some students are not able to successfully do this and find other ways to enter into a process of viable action-thought. The interpretive reconstruction which follows describes Keith's way of entering into the problem:

Keith's pop-bottle car

Keith had been thinking about the Inventing a Machine project since Ms. B. announced it to the class. During that time he noticed an activity in his science textbook describing a car building activity and decided that it was something he would like to do.

When asked to describe his idea Keith told the class that he was going to build a car. He didn't have a specific plan, he just knew that he wanted to build a car. Ms. B. asked everyone to try making a sketch that showed a plan of their idea. Keith couldn't draw anything. His response was to begin building a prototype. He found some cardboard in the storeroom and cut it into pieces. It wasn't long before he had put together a small car chassis made from cardboard and masking tape. Keith proudly showed me his cardboard car and commented that he thought it looked a little bit like a boat but that it didn't matter.

Keith knew that I had brought some hobby motors to class and asked me if he could use them on his car. I gave Keith the motors and suggested he try the wooden wheels I had in my materials box. Keith chose a pair of wooden wheels. They did not have a hole for an axle and Keith asked me how they could be connected to his motors. I showed him a partially completed construction that I had brought to class. It had wooden wheels mounted directly on the axle of the hobby motors. Keith wanted to know how he could do that as well and we went to the tools table where I helped him drill holes in his wooden wheels. Keith worked alone for several minutes, attaching the motor and wheel assemblies to the back end of his car with masking tape. He had just finished installing front wheels on his car when Ms. B. asked everyone to hand in what they had drawn. Keith had not drawn a plan, he took his cardboard car up to show Ms. B. as if to say to her "this is my plan."

During the next class Keith finished the cardboard car. He spent a lot of time connecting a battery to this car in order to get the motors going. He was pleased to finally make the car move but he was not satisfied with its sturdiness and carrying capacity. The cardboard sagged under the weight of the 100 g weight inside and the car would not move. At that point, Keith decided to build a second car that could carry an even heavier load. He found a 500 g mass in the storeroom and decided that it would be suitable.

In his second attempt Keith built a chassis and front end wheel assembly using "LEGO style" parts. He kept the hobby motors and wooden wheels from the cardboard car and mounted them on the LEGO car with masking tape. The new chassis was stronger than the first one and supported a 500 g weight. The car rolled easily on its wheels when pushed. However, a new problem emerged. The hobby motors were not powerful enough to move the car with the weight. Keith asked me how he could increase the power of the motors. First we tried connecting more batteries and then we tried using a 9 volt battery that Keith found in the toolbox. Nothing worked. Keith was determined to build a car that would transport 500 g. He said that he would try again over the weekend.

Next class Keith arrived with a new car. It included (1) a lighter chassis, (2) a more powerful motor, and (3) a smoother running front wheel assembly. On his new car Keith incorporated a battery operated rear wheel assembly that he "cannibalized" from an old toy car. A tiny "Hot Wheels style" car served as the front wheel assembly. The two wheel assemblies were attached to a cutout plastic two liter pop bottle which served as the chassis. He was very pleased with this innovation. It was lightweight and strong and rolled easily when given a push. In a test conducted in the hallway outside the class, Keith's car successfully transported a 700 g weight although it did not always go in a straight line. Keith was a little shy about and surprised by his unusual design. He commented that he thought it looked like a roller skate.

Just before Keith demonstrated his pop bottle car to the rest of the class, he warned the people sitting on one side of the hallway floor that his car might veer towards them. In the demonstration, the car consistently veered to the right, hitting the wall and stopping after going a couple of meters. One of the students suggested that it would be interesting to see if it could go around a corner. With that, the whole group moved to one end of the hallway in order to see if this idea would work. It did on the first try and everyone applauded and cheered. Keith beamed with pride. Keith, Ms. B. and I remained in the hallway a for a few moments as everyone else returned to the classroom. "Wow, it never did that before, that was good" he exclaimed as he looked closely at his car. Keith's pop bottle 700 gram transport car had become a right cornering pop bottle car.

Keith is a large, quiet, and well spoken boy. Rather than approaching me directly to describe his idea Keith approached the box of tools and equipment I had brought with me and began to pick up and look at pieces of wire, batteries, hobby motors and wheels. I noticed him doing this and asked if there was anything there that he thought he could use. Keith said that he thought he could do something immediately with some cardboard Ms. B had provided and headed to the storeroom to retrieve it.

A pattern of entering into conversation through manipulating objects and materials turned out to be typical of how Keith approached others. According to Varela, Thompson and Rosch (1991) Keith is creating his own setting - an enacted space in which he could bring forth his ideas by surrounding himself with material objects. This enacted space may be described as an **affordance space**. An affordance space is more than the setting in which a student works. It is constituted by three elements: the setting including the materials and objects; the persons; and the person's ways of engaging the setting and other persons. These three components are dynamic and interact to co-specify the affordance space. Keith could structure his ideas and to communicate them to others within his own affordance space. By the end of the class period he had constructed a working prototype of his idea.

As portrayed in the vignette Keith built two more cars from different materials. From the standpoint of an enactivist interpretation how can one describe the relationship between the three models and their contribution to Keith's emerging understanding? Did a single coherent understanding emerge for Keith or were there several? As noted earlier, it is often the case in science and technology that initial prototypes lead to subsequent developments that are radically different. In school settings it is usually the case that a student's first understanding is the one that is developed in a linear fashion to a logical endpoint. It is relatively rare that students are provided the opportunity to create their own affordance space and the time to re-shape it recursively.

In the Inventing a Machine activity students could choose to work by themselves or with others. Keith elected to work on his own and in the subsequent interview described his vision of his project in strongly embodied terms. For instance when I asked Keith to tell me more about what he meant when he talked about "knowing his machine" or "understanding his machine" he replied:

> **Keith:** Well I knew what my project was going to be from the start. I had sort of a vision shall we say, of a car, not going too fast or anything. But just moving just enough to keep a five hundred gram mass going. If you have an idea right from the beginning it sort of develops as you go along and it gets embedded in your memory. ... You know it off by heart from there.

Enactivism views understanding as a **coemergent** and **embodied** process in which both the knower and known emerge together in a relationship of mutual specification. This is the essence of what I think Keith means when he speaks of understanding that "gets embedded in your memory" and "sort of develops as you go along". Other students have expressed similar ideas when they describe themselves as being **"in an investigation"**.

Keith seems to have a strong sense of himself as being embodied in his understanding. Careful in his movements and actions, which creates an impression of intentionality, he describes his vision as "not going too fast or anything but just moving". Is he describing his car, himself, or both?

Many of the students in the grade eight classroom expressed their excitement and exhilaration for building during the project with exclamations and a good deal of movement. Keith was different. His movements seemed more deliberate. He seemed to prefer careful movements and worked sitting down most of the time. Whereas some students spoke of making things go fast or go far Keith seemed to want to construct something that embodied aspects of himself. A progression of increased sturdiness, slow deliberate movement and increased carrying capacity emerged in the design of Keith's cars. Keith did not seem to be trying to optimize any particular aspect in the design of his cars. It seemed to me that he was building them according to a shape that felt good to him and that design was embodied in his own physical being. Keith had an air of purpose about him. He seemed to know he was going to be able to succeed.

Keith seemed to visualize his idea in an enacted space. What I mean by this is that Keith talked about being able to imagine his ideas. He seemed to do talk most freely when he was involved in some sort of hands-on manipulative activity. It seems that, for Keith, expressing his understanding verbally involved being physically involved in doing.

Keith used the affordances of space and materials as a means of visualizing or bringing forth his ideas. Ms. B. provided Keith with the occasion to do this by not insisting that he present a written plan before starting to work with the materials. Ms. B. seemed to be aware of Keith's approach to his thinking in the science classroom. I noticed that Keith carried his model of the machine with him whenever he engaged others in conversation. Such conversations usually started by focusing attention on some feature of the model itself. He seemed to prefer to create a physical space or object around which a verbal discussion could begin.

As noted, Ms. B. was aware of and intrigued by Keith's approach to thinking in the science classroom. She was interested in what he had to say during his conversation with me. When I told her that Keith had said that building was a central part of his thinking she said that she had noticed that he seemed to work best when he was engaged in that kind of classroom activity. The classroom aspects of the building projects are discussed in Chapter 8.

Keith's embodied understanding was reflected not only in the design of his cars. It also emerged in the nature of his interactions with other students in the classroom. Keith seemed to enjoy observing and operating the machines other students constructed and talking about these other projects. The experience of being immersed in a community of builders provided Keith with a more complex understanding of that community and of his way of being in it. I noticed that Keith would return from time to time to briefly play with one project in particular. Keith would joyfully operate the cactus watering machine (described in Chapter 7). It seems that such occasions allowed Keith to extend his affordance space. Being able to interact with other students work is a form of communication for Keith in the sense that it allowed him to see significance in the way others were developing their ideas and it allowed others to see that their work was significant for Keith.

Is there recursion in the sequence of events enacted by Keith? Was Keith working on three different projects or was he working on one project? The laying down a path metaphor while implying a sense of directionality does not in its detail imply a linear progression toward a specific pre-defined outcome or goal. There were aspects of recursion included in Keith's building three separate cars in the sense that he revisited the image of a vision of his car moving slowly but steadily. His second model, while the least successful of the three, served to focus his attention on finding a new chassis that was light and strong.

In his first construction Keith used cardboard pieces he cut out and masking tape to construct a small car chassis. but found that it was not strong enough to support a 500 gram mass. In his second car Keith built the entire chassis from plastic "LEGO style" building blocks which although it was strong enough was too heavy for the hobby motors to move the vehicle. Keith's thinking became more diversified in his third car. He found that a two liter plastic pop bottle provided a material that satisfied his criteria for a chassis that was both strong and lightweight. The general criteria for the properties of the materials in Keith's car emerged in his enactions of his earlier cars. Would Keith have been as concerned about locating a very strong and light material for his third car had his second car not been too heavy? The metaphor of laying down a path in walking does not imply a level and easy navigable terrain. As the obstacles present themselves new ideas and directions emerge. I will explore aspects of such paths in Chapter 6 which focuses on the complex and recursive process of coming to understand the problem.

Ms. B. asked her students to provide a diagram that included a detailed drawing of their machines and to design and construct a flowchart which described how energy was involved in their machine and how it worked at various stages. Figure 4 depicts Keith's rendition of his diagram. It contains a flowchart (in Keith's own handwriting) and a set of pictures describing various components of his car.

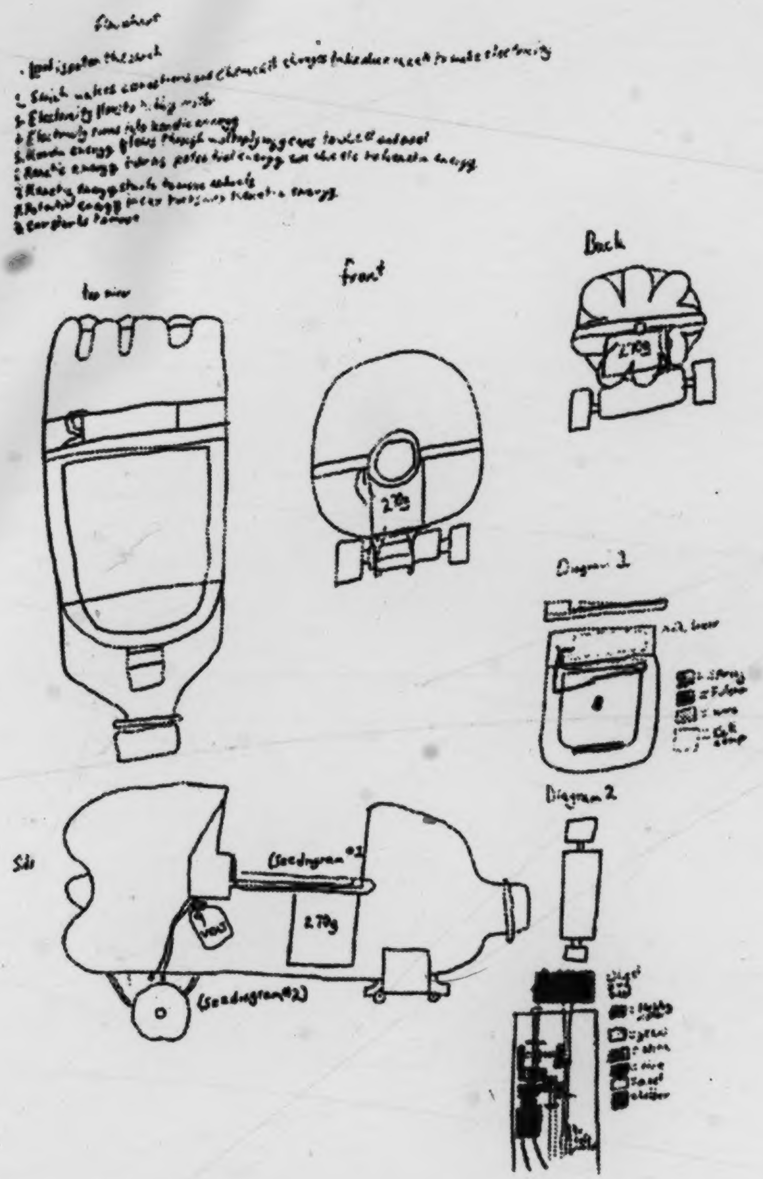

Flowchart
top view
front
Back
270g
Diagram 1
Diagram 2
Side
(See diagram #2)
(See diagram #2)

Figure 4: Keith's diagram describing his car

Figure 5 presents a more readable typed version of the handwritten flowchart (depicted in Figure 4) or path laid down by Keith to explain the workings of his car.

1. Load is put on the switch.
2. Switch makes connections and chemical changes take place in cell to make electricity.

3. Electricity flows to hobby motor.
4. Electricity turns into kenetic (sic) energy.

5. Kenetic (sic) energy flows through multiplying gears to wheel and axel (sic).
6. Kenetic (sic) energy turns potential energy (from?) wheels to kenetic (sic) energy.
7. Kenetic (sic) energy starts to move wheels.

8. Potential energy in car turns into kenetic (sic) energy.
9. Car starts to move.

Figure 5: Keith's flowchart describing the workings of his car

One way to interpret Keith's flowchart is to focus on understandings which are apparently revealed as specific conceptions in Keith's description of the workings of his car. Keith appears to view energy as a material substance which has the capability to flow from one place to another and from one form to another. This idea seems to be interwoven with his view that electricity flows from one location to another and can be transformed into kinetic energy.

A second conception involves Keith's views of kinetic and potential energy. Keith seems to view potential energy as something which is inherent in a stationary object (such as his car or the wheels of his car) that has the potential to move. Keith seems to separate kinetic energy into two forms, a flowing kind that moves from one place to another and an intrinsic kind that is contained within a moving object. It seems that Keith considers the first kind of kinetic energy to act as a catalyst to initiate the transformation of potential energy into the second kind kinetic energy within an object. It is the second kind of kinetic energy that is responsible for the motion of his car.

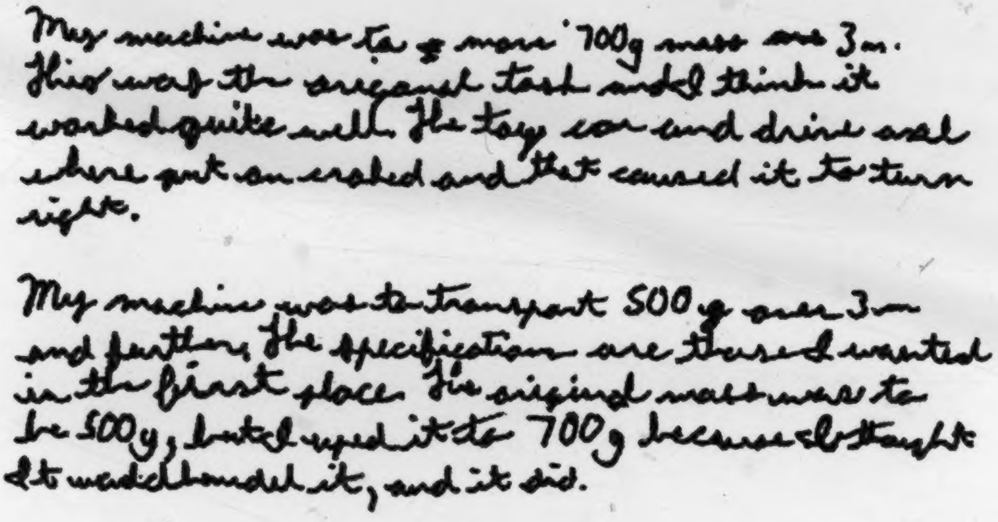
A constructivist approach to an interpretation of Keith's understandings as revealed in the alternative conceptions embedded in his writings allows a researcher to identify some interesting and provocative aspects of his knowledge. However, such an interpretive approach does not allow a researcher to characterize and interpret understanding as a process.

A second way to interpret Keith's flowchart is to consider it as one part of a larger and more holistic process of understanding than that which is developed by a constructivist approach. For instance, Keith provided a series of drawings to supplement the explanation he provided in the flowchart. These drawings (see Figure 4) are special in that they depict multiple views of Keith's machine (i.e. side view, top view, front view, etc.).

Why did Keith provide multiple views of his car? It seems that Keith's thinking was influenced by several physical aspects of his car which emerged as the project progressed. First is the idea of slow motion movement. This seems to have been an aspect of Keith's car that was determined by his choice of the motor assembly which he scavenged from a toy at home. However, this was also determined by something within Keith himself. Keith seemed to prefer to use the slower moving geared motor rather than the faster moving hobby motor I had originally provided not only because it was more powerful but also because its motion resonated more closely with the kind of action-thinking he wanted to do in this project. The "multiplying gears" of Keith's motor allowed him to see, feel and envision energy moving from the battery to the wheels of his car.

At another level the whole project had a "slow motion" aspect to it in the sense that it was extended over several class periods and took longer to complete than a more typical classroom activity. Keith was not a "slow" thinker. On the contrary I found him to be quick to develop ideas, eloquent in his description of them, and forthright in his actions to put them in motion. Nonetheless there was a deliberate quality to the nature of Keith's way of being in the science classroom that was unique to him. He seemed to like to have his own space within the classroom within which the agenda for action was controlled by him. It may well be the case that aspects of the environment in which Keith acted changed in such a way that they became more like him and that as he shaped the environment in which he worked it continued to become more like him. In this sense Keith and his environment for action-thought became a co-emergent embodied entity.

Second, Keith's car was essentially transparent in that it used a clear plastic pop bottle for a chassis. This notion of transparency is important because it allowed Keith to engage and act toward his car in a way which had an impact on his thinking and understanding. Keith spent a good deal of time holding his car up and looking intently into it. This kind of action may have influenced and allowed Keith to think about and develop a more complex way to describe and explain the workings of his car. Keith was not a student who was renowned for verbose or extensive detail in his written explanations of his work. For instance, one written description that Keith provided Ms. B. for his work in this project is presented in Figure 6:


My machine was ta move 700g mass 3m.
This was the origanal task and I think it
worked quite well. The toy car and drive axal
where put on croked and that caused it to turn
right.

My machine was to transport 500g over 3m
and further. The specification are those I wanted
in the first place. The original mass was to
be 500g, but I uped it to 700g because I thought
It would handel it, and it did.

Figure 6: Keith's written description of his project

Figure 7 presents a typed version of Keith's written description (depicted in Figure 6).

My machine was to move 700g mass 3m. This was the original task and I think it worked quite well. The toy car and drive axal (sic) where (sic) put on croked (sic) and that caused it to turn right.

My machine was to transport 500g over 3m and further. The specifications are those I wanted in the first place. The original mass was to be 500g, but I uped (sic) it to 700g because I thought it would handel (sic) it, and it did.

Figure 7: A typed version of Keith's written description of his project

If this were the only thing a teacher or researcher had access to in order to assess the understandings Keith developed during this project they might easily conclude that Keith either did not develop much new understanding or did not communicate these understandings very well or both. However, the understandings which Keith developed in doing this project were embodied in much more than the written discussion he provided as a part of the project. Keith's actions and ways of engaging the world around him evolved during his involvement in this project and constitute an important and essential dimension of the understandings he developed. Keith's rather terse and summarial written description of his thinking (as presented above) does not allow the reader to grasp the process oriented way of communicating his thinking.

The development of this kind of thinking was partly a consequence of Ms. B.'s project requirements but also an outcome of the way Keith was able to physically enter into his thinking through building and testing his car. The emergence of Keith's description of a "vision" which became progressively clearer and more differentiated and the improvement in his ability to communicate his thinking from multiple perspectives are indications that Keith considered himself to be laying down a path in his activities. This vision was communicated best to me when Keith enacted his thinking during the actual doing of his project as opposed to the re-telling of his story in the interview.

What did Keith learn? First, He learned that a project can evolve and develop in a recursive pattern where some ideas are included and some ideas are discarded as action-thought develops. Second, Keith learned about how he could include an "outlandish" aspect of himself in his way of acting and his car and still be viable and successful in the classroom activities. Third, he learned about the importance of connecting qualities of himself to qualities of his way of engaging in action-thought. The way one acts and engages their world in a classroom needs to resonate with who they are as a person. **Laying down a path in walking** requires that a person enacts a viable way for "walking" or engaging their world. This can only be established if a person can see themselves as being embodied in the processes of "walking" or engaging in action-thought. Figure 8 presents Keith's written responses to the reflection worksheet.

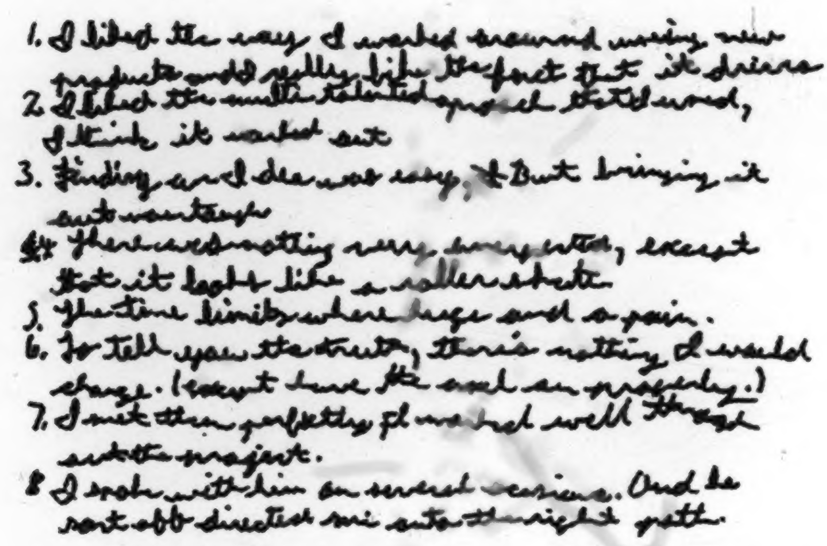


Figure 8: Keith's written responses to the reflection worksheet

Figure 9 presents a typed version of Keith's written responses (depicted in Figure 8) to the reflection worksheet.

1. I liked the way I worked around using new products and I really like the fact that it drives.
2. I liked the multi talented approach that I used, I think it worked out.
3. Finding an idea was easy, but bringing it out was tough.
4. There was nothing very unexpected, except that it looks like a roller skate.
5. The time limits where (sic) large and a pain.
6. To tell you the truth, there is nothing I would change.
   (except have the axel aim properly.)
7. I met them perfectly, I worked well throughout the project.
8. I spoke with him on several ocasions. (sic) And he sort off (sic) directed me onto the right path.

Figure 9: A typed version of Keith's written responses to the reflection worksheet

How does this episode contribute to our understanding of classroom learning? As educators we need to recognize that the degree of the control that a learner has over his/her environment is an important factor in allowing the learner to enter into a process of developing understanding. Students do not always need to be told how to accomplish a task, they can establish that for themselves. A task environment which provides learners with an opportunity to shape their environment allows them to take ownership of it. I will deal with the classroom implications of these issues more fully in Chapter 8.

Evolving conceptions of adequate conduct: Dynamics of viability

My second vignette is situated in the grade nine extended research engagement, **The Solar House** project. This research setting differed from that of the Keith vignette in that the overall goal of the assignment was articulated by the teacher to be the same for all the participants. Also present was a competitive aspect in that measurable criteria were developed that allowed students to compare the outcomes of their work on quantitative criteria for performance. The vignette I will now describe involves three girls Helen, Karla and Laura engaged in an activity which was a precursor to the design and building of the solar house. Helen and Karla worked together and Laura worked alone. However, the three girls worked in close proximity to each other during the ice cube project and later collaborated on the solar house project.

After studying a unit involving the physics of heat transfer the class was presented with a challenge: to use their knowledge of heat transfer and properties of materials to invent a container to keep an ice cube of standard dimensions from melting for as long as possible. Students were encouraged to try a variety of things. The class was given a short time interval (about two days) to design their thermal insulation container. On the day of the challenge ice cubes of roughly equivalent size were distributed and weighed before being placed in the containers. After approximately three hours the ice cubes were re-weighed in order to assess the performance of the containers.

I have chosen this activity to illustrate the dynamic nature of a key enactivist idea, namely **adequate conduct**. Maturana and Varela (1987) interpret adequate conduct in its biological sense i.e. the organism either survives or fails to survive. If it survives then its conduct is designated to be adequate. In social settings manifestations of adequate conduct or viable action are not as readily apparent in the sense that the notions of adequacy are much more contextual, fluid, and temporally bound. The notions of adequacy are also individual in nature in the sense that they rest on not only the individual's interpretation of the task but because they depend on the individual being able to see or envision a pathway to success. What is adequate at one time or in one setting may not be adequate at another time and/or in another setting. Both the biological and the socially mediated stances toward adequacy are proscriptive in nature i.e. there is no single correct description of adequacy. If the conduct is viable, it is adequate. The portrayal which follows reveals some of the complexity of the development of idea of adequate conduct in the context of a science classroom.

Ice-cube box challenge

Ms. B. has given her grade nine class a challenge to design and build a container that most effectively insulates an ice-cube from the temperature of the classroom. The effectiveness of the designs will be assessed by measuring the fraction of the mass of ice remaining after a known time interval (about two and a half hours).

Most students select the largest and most impressive items they can find from the materials provided. Items such as puffy rolls of cotton and pink fiberglass along with sheets of extra thick styrofoam are most popular. In fact, including something made from styrofoam seems to be considered essential. The classroom becomes immersed in sounds of duct tape being unfurled and styrofoam sheets being cut into pieces.

In their usual corner of the classroom, Karla, Helen and Laura are discussing what they will do. Laura already has an idea and decides to work on her own while Karla and Helen decide to work together.

Karla and Helen make their way to the materials area. They choose a small but sturdy paper light bulb box. They seem pleased with the stiffness and strength of the box and they squeeze it and comment that it feels good to them. Helen notices some multicolored styrofoam packing chips in the materials area. "These look kind of neat" she says as she picks them up for a closer inspection..

Karla and Helen spend a lot of time arranging the styrofoam chips in the bottom of their light bulb box. "They ought to keep the ice-cube from touching the sides of the box and besides, we know styrofoam is a poor conductor" comments Helen. Their attention shifts from the inside of the box to its outside and this leads to the incorporation of other ideas to reduce heat transfer. First they wrap their box with fiberglass insulation and plastic tape to reduce conduction and convection and then they encase the whole box with aluminum foil to reduce heat transfer by radiation. They announce to Ms. B. that they are ready to test their ice-cube box.

Laura fills two styrofoam cups with pink fiberglass insulation and tapes them end to end to form a closed container. While other students build more complex containers involving layers of styrofoam, vacuum pumps, insulation soaked in alcohol, tape, and glue, Helen and Karla's box is dwarfed by comparison. They are convinced its performance will be more modest than any of the others.

On the day of the test Karla and Helen measure the mass of their ice-cube and place it inside their box. Everyone places their ice-cube box in the adjoining storage room. Karla and Helen are not confident that their box will perform well and just before they leave Karla places a cardboard box over it to protect it from the light. Laura is more confident and leaves her construction in a more exposed place. Everyone shares a strong sense of anticipation for what they will find when they open their boxes.

When the students open their boxes they measure the mass of the remaining ice-cube. Consternation abounds when some of the most elaborate designs reveal nothing but water. To the amazement of everyone, Karla and Helen's ice-cube box emerges as the best. Laura's design also works fairly well.

Many students are perplexed with the relatively poor performance of their containers in the test, especially in comparison to Karla and Helen's simple design. When Ms. B. offers everyone a chance to redo the activity, Karla and Helen decide not to do this. When she compares her design to those developed by other students, Helen offers an observation. "Ours was just a light bulb box with styrofoam in it and it worked, and we got the most left at the end ... and everyone else's were like these big elaborate things. I think sometimes simple is best."

How is the notion of adequate conduct socially mediated and how is it personally mediated in this case? Was the ice cube container exploration a viable engagement for Karla and Helen or Laura? On first inspection it appears that Karla and Helen's conduct in this exploration was viable. Ms. B. was certainly pleased with what they had accomplished in this activity and her assessment of their performance reflected that. At one level the girls were also satisfied because they declined an opportunity to repeat the ice-cube activity which many other students accepted. While they were satisfied with their grade in this activity the context of their success emerged as problematic in the course of my extended interview with them when both the ice-cube activity and the solar house projects had been completed[1].

> **Leo:** What do you think some of the other students in the classroom thought of your project?

The discussion which emerged from my prompt focused on how the girls went about building their solar house. Eventually their conversation spontaneously turned toward the ice-cube box activity.

> **Helen:** ... Like with the ice-cube experiment, the first time we did that it was like, we Won!
>
> **Laura:** We just look at the projects that are more elaborate to see ... like for the ice cube, remember Dan with this big vacuum and all that stuff (laughs).
>
> **Helen:** Huge.
>
> **Laura:** It was really interesting to see what's going to happen.

> **Helen:** But it didn't work at all. There was nothing left. He had, him and Jill and Tristen, this huge elaborate system with vacuum pumps and all this styrofoam and there was no ice-cube left at the end. Ours was a light bulb box with styrofoam in it and it worked. Ours was the most left at the end. Everyone else were like these big elaborate things. I think sometimes simple is best.
>
> **Laura:** Except mine.
>
> **Helen:** Except for Laura's with the styrofoam cups. But it didn't work either (laughs). No it worked. Laura's did good. Better than some people's did. Which is not really the point of the experiment, to see who did the best. It's to see, to learn some thing from your mistakes and to learn something from the people who did better.
>
> **Laura:** Or did worse.
>
> **Helen:** Or did worse. See what didn't work, what other people had, what did work.

The excerpt above illustrates several aspects of Helen's conception of adequate conduct. At one level Helen is pleased with the outcome of the activity ("We won!"). On a social level there is ambivalence. While pleased with their performance relative to other more elaborate projects submitted by perhaps more admired members of the class Helen also expresses sensitivity for her friend Laura's relative lack of success. For Helen the notions of viability shift from the performance of an individual ice-cube box to the connection that project has with other students projects in the classroom.

The point of the ice cube activity shifted to allow students to learn from personal experience and observation of other ideas in action. The purpose of identifying which ice cube container design performed best was to serve as a way to learn from experience. The agenda of using that same performance as a grounds for evaluation was no longer acceptable for her. In fact it was now seen as interfering with her way of thinking because the competitive component of this activity encouraged some students to refuse to share ideas.

> **Helen:** Yes. Some people may have found this experiments really interesting. Like the ice-cube thing I thought "well it wasn't really exciting, but it was sort of really neat to ... figure out a way for it to work". But it was just ... so much of it was based on ... it was a competition ... you had to do better than everyone else and you're supposed to get the best one. I don't like that. I don't like the competition. Well, in a way I do but it shouldn't reflect in your marks.

The viability of a student's thinking is not necessarily strongly tied to the quality of the outcome of the work they produce. Teachers and educators typically associate the processes of thinking with the products of thinking. An unsuccessful outcome is associated with a flawed process of action-thought and a successful outcome is indicative of a viable sequence of adequate conduct. However this is not necessarily the case in activities in which a high degree of self-directedness and open-endedness are present. These kinds of activities provide an occasion for students to get a sense of the viability of processes for engaging in action-thought and developing their understanding. Helen is obviously aware of this aspect of her engagements.

As educators we tend to view the products of students' work as a medium through which they can communicate their understandings to us. This perspective assumes that students' understandings are embodied in the work they produce. However, students' understandings are also embodied in the action-thought processes they enact as they develop understandings and the action-thought processes which emerge as a consequence of their engagements. In other words, student understandings are both a process and a product which mutually specify each other.

The following excerpt reflects the level of conceptual understanding that Karla and Helen had while they were engaged in the ice cube activity. They did not feel comfortable about winning the competition because they did not understand the reasons they were successful. From the standpoint of viability a scientific explanation of why their project was successful did not emerge nor did the look for an explanation. They seemed to look first for explanations that were external to the design of their box - i.e. the environment. Helen and Karla never did develop an explanation with which they were satisfied for the performance of their ice cube box. Other students were equally perplexed. One student in particular commented to me a couple of weeks later that he was still mystified about how such a simple design did so well. By that time I had an idea of my own and I suggested it to him as a plausible explanation. I told him that I thought that the melting rate of ice might depend on whether or not it was wet - i.e. a wet ice cube sitting in its own melt water might melt at a different rate than a relatively dry ice cube. He nodded his head as if to agree with me but was not interested in testing the idea any further.

> **Helen:** We worked hard on ours (frowns at Karla).
>
> **Karla:** Not really.
>
> **Helen:** But by luck or something, theirs didn't ... like the people who put less effort into it may have gotten a better mark just because their idea happened to have worked.
>
> **Laura:** By a mysterious way.

Helen: Yes, by mysterious ways. Yes. We put a new ice-cube in half way through (laughs at the suggestion of cheating). No. No, we didn't do that.

Karla: We also put it in a dark place.

Helen: ... We did sort of cheated, there was this ... I don't know.

Laura: You didn't really cheat (looks concerned).

Helen: Well, we didn't REALLY cheat.

Laura: No, you had the right to put it wherever you want.

Helen: It was like two boxes, two boxes that were without lids and I put it inside one and flipped the other one on top of it in a dark cold corner. So I think that's partially why ours worked better.

Karla: Uh huh (agrees).

Helen: I don't know. Someone put theirs in the window, which I have yet to understand (laughs). Because you can see the window here (window in interview room) from the LA (Language Arts) room and the day of the ice-cube thing someone's box was in the window. I thought that was really stupid. Because you were supposed to keep it cold, not make it hot.

The girls' perspective on what they are doing changes as their understanding evolves. Their engagement with the environment provided by the ice-cube box and solar house activities opened up a number of competing agendas. Figure 10 presents Laura's, Helen's, and Karla's drawing of their solar house. A drawing of their Ice Cube box was not available.

1.a) We surrounded the house with black paper which absorbs heat. This idea wasn't very successfule.

b) We lined the box with test tubes filled with water.

c) We lined the house with black paper and the walls were made of Styrofoam. and fiberglass.

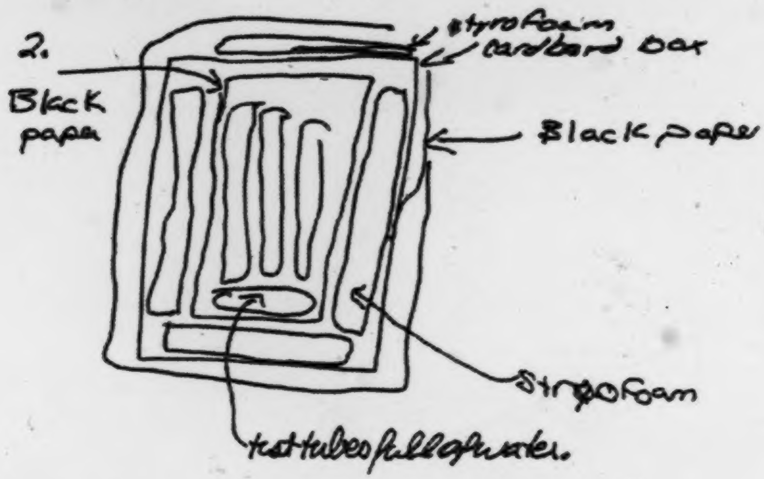


Figure 10: Laura's, Helen's, and Karla's drawing of their solar house

Working in a self-directed way on a more extended project was something they valued and contributed to them working productively. However, they recognize that there were aspects of these activities in which they were not fully implicated. Laura's comments suggest that new attitudes and perceptions about the nature of her engagements in science have emerged from her experience in these self-directed activities. The excerpt which follows pertains to my explorations with the girls as to how they compare doing textbook science activities to activities in which they are able to construct their own solution to a task or problem.

> **Leo:** Is there a scientific procedure that you would normally follow that is different from the procedure you used to do the solar house project?
>
> **Laura:** What do you mean scientific procedure?

Leo: ... I was hoping that you could tell me. ... Are there things that you do when you do other activities in science?

Laura: We don't have the time to do a procedure in activity in science...We have maybe five minutes to do an experiment and we usually never made it on time.

Helen: Yes. We almost never get our ... (Laura interrupts)

Laura: Never, because we have five minutes and we had to get our stuff ... we have to do the things and we have to do the analysis and in five, maybe ten minutes. So we don't have the time to really sit down and do a procedure.

Leo: OK, so you don't think about observing specific things or hypothesizing or drawing conclusions?

Laura: Oh yes! Oh yes! We have that all on a sheet of paper.

Helen: Yes.

Karla: Yes ... when we do experiments we usually have a procedure in our mind. We just, "OK, first we'll do this, and we just do it". But we don't really write it out and say "OK, first we're going to (long pause)". You know?

Helen: Usually it's written.

Karla: There's a procedure in the book, yes.

Helen: Yes. In the book, in the science textbook that we follow, mostly. (laughs)

Laura: When there's a question that we have to concentrate, to focus on.

Helen: Yes. The analysis.

Laura: So it's kind of done for us. We don't need to sit down and agree with the procedure in the book or nothing.

Karla: We just do what it says.

Laura: Yes. We just, well we don't have to, because we don't have much time.

Leo: Is that different? Doing science that way ... as compared to what you did on the solar house project? ... following the directions of the book?

Helen: Yes. Well that's a different way of ... it's different because you don't have any say in what's going on. **It's not what you think would work, it's what the book says will work** and sometimes it actually works but it's different because you don't get to think about it. **You don't get to ponder scientifical (sic) questions and things.**

Karla: Yes, with the solar house you just did what you wanted or what you felt would work.

Helen: What you thought, hoped would work.

Karla: Hoped would work.

Helen: Key word there, hoped. But it was interesting.

Leo: Would you say that the solar house project was a riskier approach to doing a project than an approach where you follow directions from your textbook ?

Helen: Sort of, because in the textbook it's an experiment that's been done before and you know that it will work. With a solar house it's more fun because you don't know if it will work or not and you just experiment with it and you get to put your own ideas into the experiment. (Karla nods in agreement)

Laura: Yes, I agree and we had more time too. That's a factor that's very important.

Helen: Yes, and there was more time to do the solar house than some of the others.

Laura: Well, we had to do it in a week.

Helen: We had more than ... Oh, I think we had two weeks. I'm not sure. I don't remember. It was a while ago but it was different than most science I've done.

Laura: Because we do it ... maximum fifteen minutes to do the experiment usually and now we have two weeks.

Helen: Yes, so we think over it more as in when we do other experiments in class. It's sort of, I do it really quickly and you hope you get done by the time the bell rings or whatever, which almost never happens.

Laura: Yes, or you don't have the time to understand. You just do what's done and you have to take your time at your home to really look at what you did and understand. Solar House, **you understand first and after that you do it**

Helen: Yes, or you sort of while you're doing it become ... get to be understanding of what's going on more than you do in some experiments when you're just doing it and it actually works and you don't know why or how or whatever.

Laura: Because it's time factor.

Helen: Uh huh (agrees)

Leo: Tell me more about that ... the time factor ... when the time factor is longer ... that is good?

Helen: Yes.

Laura: Oh yes. That's good. Now we have fifteen minutes to do an experiment and we just do what the book said and we just don't argue with the book. Just do it. But when you have more time, well personally I can just think about it first and after that understand what's really going on instead of just "don't know what's going on and just do it".

Helen: Yes. Being able to sit through the experiment and to understand each part of it and not just understanding a little bit of it or not understanding it at all. You get to look at it and get to say "well this is what I think will work" and find out it doesn't. But it's (activities from the book) an easier way of understanding things because you have the extra time to sit there and read what the book says, well if you happen to be doing one from the book. Read what the book says, think about what you think is right and what other people in your group think is right and what your teacher thinks is right, which is probably wrong. (laughs)

Laura recognizes that having activities selected for her is a constraining factor to her thinking. She points in the interview to time as a constraint and the pressure to complete activities without really understanding them. Helen on the other hand does not agree. Helen suggests that having time to read the textbook contributes to her understanding. I wonder if Laura would even raise this as an issue had she not participated in this self-directed experience. Laura's point is worth noting. Students need to feel implicated in the design and execution of their learning activities. When students become deeply immersed in their learning it seems that they can begin to recognize important aspects of the process.

What have these students learned about viability and adequate conduct? Karla, Helen, and Laura learned that viability in their science activities emerges as much from their own engagements with their environments as it does on the nature of the environments themselves. Outcomes can be viewed as successful when viewed from one perspective and not as successful when viewed from another. This is powerful because it demonstrates that the girls recognize and acknowledge a central component of enactivism i.e. the implicit role of the observer in determining what counts as knowledge. Adequate conduct is about becoming a part of your environment and shaping it through the ways you choose to engage it.

The girls recognize that there is more than one correct way to act and more than one viable set of knowledge claims that can emerge from their engagements in science class. The recognition by the girls that viability and adequate conduct are proscriptive in nature lends powerful support for the ideas found in an enactivist approach to interpreting classroom thinking and the development of understanding. It also highlights a fundamental distinction between enactivism and constructivism as interpretive perspectives in the sense that while constructivism recognizes the importance of considering multiple alternative forms of understanding it implies that there exists only one form of understanding which is viable, namely the so called scientific view.

I believe that students are implicitly aware of a teacher's or researcher's epistemological views. If this is the case then what impact does a teacher's view on what constitutes viable understanding have on the nature of student actions to develop such understandings? It seems to me that the proscriptive view of viability which emerges from an enactivist perspective offers more possibilities for students to find their own successful action-thought pathways to develop understanding than the more prescriptive view which is provided by constructivism. This is a central component of my argument in favor of adopting a more proscriptive approach to viewing student knowledge and the pathways they enact to develop their knowledge. This idea will be explored further in Chapter 8.

A way to think of experience

Our histories of **structural coupling** emerge and take shape in present action. In a sense, the present embodies both the past and the future. Past and future emerge and take shape in our enaction of the present or in our bringing forth a world of significance. Another way of saying this is to say that the past and future are re-invented in the present ... we continue to communicate with, interact with and have an autopoietic relationship with our past and future through our experience of the present. Picture a wiggly string of infinite length which can be fixed at one point. The string describes a kind of trajectory which passes through the fixed point. The fixed point represents present experience and the other two segments past and future experiences.

Action-thought is enacted in the present and simultaneously projected into the past and future to create a world of significance for the individual. The degree of coherence which emerges from the past-present-future triad determines the quality of enacted experience and may have implications for its viability.

An important theme which has emerged from my engagements with students involved in extended self-directed explorations is the notion of "getting it to work". Investigations and explorations that are suggested from the textbook are considered to be qualitatively different from those done in a self-directed way. Laura and Helen describe textbook activities as lacking a component of anticipation as compared to self-directed activities. One expects textbook activities to work and so one does not enter into an action-thought pathway in the same way as when one is unsure of what exactly will happen. How is an action-thought progression different when one looks for what might happen as opposed to what is supposed to happen? The students in the ice cube and solar house projects certainly delineated a clear distinction in the nature of their thinking during each kind of activity.

Student comments suggest that some students enact future outcomes for their present actions. However, the degree or intensity of structural coupling between present actions and potential outcomes may depend on how a student perceives herself to be involved in the process of bringing about the future. If a student considers herself to be involved in reproducing a pre-defined action pathway toward a pre-described outcome then what is left to be brought forth? What is left to be enacted? An enactivist approach to learning requires a strong coupling between a person's physical involvement in present action and the near past and the near future. This gives present action a dynamic temporal structure in that present action generates new potential pathways and those pathways interact with present action (in a sense the future folds back into present action). This process of constantly reinventing the present by continuously opening up new potential futures allows us to become embodied in a process of action-thought. This process may be an essential component which allows us to view our thinking as a process as opposed to a product.

One way to think about action-thought pathways is to consider them as emerging from a continuum or from a background of pre-existing pathways. This is a representationist position. An enactivist perspective is that action-thought pathways come into existence only in present action.

Karla, Helen, and Laura were able to describe a range of potential tests they could have done on their solar house during the project. In the interview they said that the reason they did not engage in this was because they did not have enough time. It seems that "getting it to work" was the predominant concern for the girls and that testing would only interfere with the optimizing process. In this sense the whole project was a kind of "one shot affair" for the girls. The test at the end was, for them, not so much a scientific test as it was an evaluative test to determine their grade for the project.

Recursive structural coupling between persons and setting

Maturana and Varela (1987) use the term structural coupling to refer to the point at which cognition and environment become simultaneously enacted. In any developing understanding one challenge is to find ways of expressing initial ideas so that other members of the group can grasp enough of the idea to be able to collectively engage in perceptually guided action. Working **in** a group is not the same as working **as** a group.

The vignette which follows describes a car building project developed by Tim and Mark as their part of the grade eight **Invent a Machine** project. The account incorporates two levels of description. One level describes the collaborative engagements of the two boy in building and testing their car in order to meet the requirements of the project. A second level describes their engagements from a personal perspective and interprets each boys actions in terms of considering the other boy to be a part of the setting. If one views structural coupling from a perceiver dependent perspective then the other members of the group become part of the setting with which the person with their own personal history of their being in the world is coupled. At a personal level one can identify enaction as being most salient to the act of bringing forth a world of significance while at a social level one can identify co-enaction as the process involved in bringing forth a different world of mutual significance. How a personally enacted world and a socially co-enacted world are structurally coupled will also be discussed. Finally the implications of structural coupling on the development of viable understanding will be discussed.

Tim & Mark's CO_2 powered car

Tim and Mark' idea was to build a rocket powered car. Tim wanted to make something that could go fast and carry a load. Mark wanted to do something original. The fact that they were the only students who planned to use rocket power was important to him. Ms. B. liked their idea but was concerned about the safety of using solid rocket fuel. She asked the boys to think of some other ways they could power their car and suggested that they talk to Mr. T. (the industrial arts teacher). Mr. T. suggested a safe alternative. He told the boys that he knew of CO_2 powered cars which could go just as fast as most solid fuel devices. That was good enough for Tim and Mark and they began thinking about how to build a rocket powered car using CO_2 cartridges.

The materials for building the car were provided by Mark. He had a collection of plastic building blocks known as "Constructs" at home which he brought to school. Tim, who already had some expertise with using hobby rocket engines, provided several CO_2 cartridges.

The building began immediately. Attaching a CO_2 cartridge onto the plastic chassis became the most pressing problem. At first they tried taping it to the outside of the car. When they tested this design they found that it was difficult to keep the CO_2 cartridge securely fastened to their car because a wet condensation formed on the cylinder as it discharged its gas. They decided to embed the cylinder inside the plastic frame. A lot of time was spent making adjustments to accommodate this design change. They built and rebuilt their car several times as they attempted to improve their design. Three areas needed attention: (1) getting the car to travel in a straight line; (2) making the car go as fast as possible while carrying a load; and (3) incorporating a third simple machine into the design. Tim and Mark attempted to solve problems (1) and (3) together. They tried using a tightly stretched string looped through a pulley which was attached to their car as a guide to keep it moving along a line. While this attracted a lot of attention from the class it did not work. The boys invited me to help them with the problem but after several failed attempts everyone agreed to abandon the idea. Getting the car to travel in a straight line remained an unresolved problem.

Mark discovered how to incorporate a third machine. In a conversation with Mr. T. he learned that an aerodynamic wing could be thought of as a kind of wedge. He adapted the "Constructs" to develop an air foil by covering the front section of the car with construction paper. He referred to it as a "wind wedge". Mark seemed pleased with this contribution and experimented with many slight modifications to its design. These explorations continued even after the car was demonstrated to the class.

Meanwhile, Tim focused on solving the problem of increasing the cars speed and distance traveled. As he discharged several CO_2 canisters he discovered that the amount of thrust generated depended on the size of the hole made in the end of the cylinder. Tim made these holes with the end of a sharp pin. First, He tried using pins with different diameters before settling on one that seemed to work best. Second, he found that the size of the hole depended on how he hit the end of the CO_2 cylinder with the pin. He continued to explore ideas about how to improve this process even after the class demonstration.

When demonstrated to the class, the car did not perform as well as it had in earlier tests. The boys were only slightly disappointed by this result. Tim and Mark continued to talk about how they could extend this project further.

Figure 11 presents Tim and Mark's depiction of their car design.

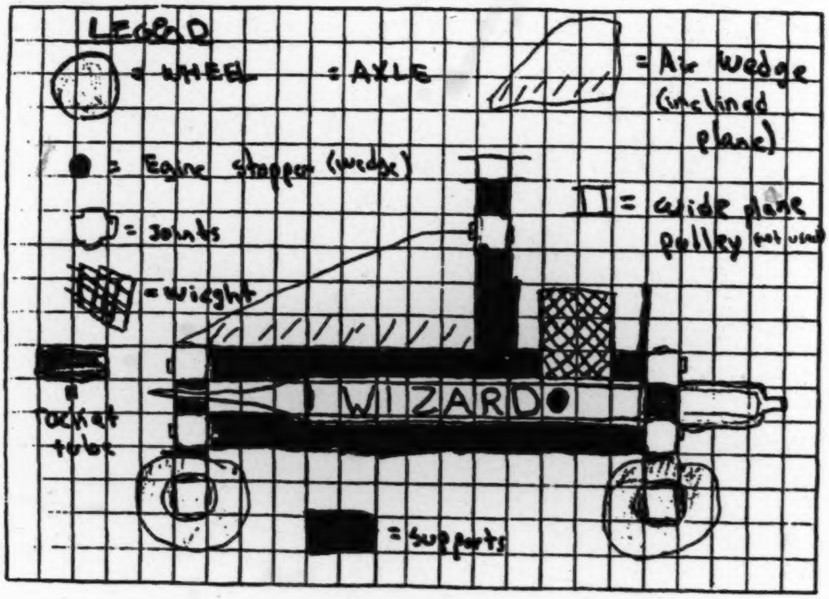


Figure 11: Tim's and Mark's depiction of their car design

When more than one person is involved in constructing a problem setting, what constitutes the problem or the setting is different and unique for each person. Varela, Thompson and Rosch (1991) make the point that our ongoing interpretations emerge from our capacities of understanding which are rooted in the structures of our biological embodiment and personal history and are experienced within a domain of consensual action. Tim and Mark saw the problem in different ways as a function of their own interests. Each was structurally coupled to the dynamic environment they were co-specifying and co-enacting in a way that was mutually determined. They were able to work cooperatively and successfully together because for Tim, Mark and his ideas and actions were as much a part of the problem setting as were the physical apparatus which they were developing. Conversely, for Mark, Tim and his interest in the CO_2 cartridges was part of the setting in which he developed the car. Both Lave (1988) and Varela, Thompson and Rosch (1991) emphasize the dynamic properties of settings which include a social dimension in that they include other persons and hence language, culture, etc. as well as material objects.

Nevertheless both Tim and Mark followed different action-thought trajectories within the overall goals of the project. Tim's thinking was focused on understanding the CO cartridges and how they influenced the motion of the projectile (i.e. the car). Mark's explorations focused on the geometry of the car and its various components, most notably the "wind wedge". He continued to shape and reshape the car throughout the project and made sure that it included three simple machines. Each boy's learning was complementary to the other's in that each thought-action trajectory influenced the dynamical evolution of the setting. Never the less each boy was experiencing the project differently. Were they also learning different things? For Varela, Thompson and Rosch (1991) the answer would clearly be "yes" as it would be for the radical constructivists. In teaching we normally assume that students engage and experience a common setting when they work together. An enactivist perspective rejects this assumption.

If we move from a consideration of individual experience to a broader level of analysis of the events in this project, what appears discrete at one level becomes a more cohesive structure at another level. The scope of the project also expanded beyond the confines of the school project. Even though the car did not work particularly well in the class demonstration the boys were not disappointed by this. They used this event to bring forth a whole new array of questions they wanted to explore. This foreshadows the idea that structural coupling may have recursive elements. Recursion involves a person's entry or re-entry into a sequence of action-thought and a shaping or re-shaping of their ways of engaging a problem setting.

In the final interview both Mark and Tim spoke of their desire to extend their project further:

> **Mark:** Well, the problem we had with this was getting it to go. So I just thought of something that we could [do to] reduce the weight by over half (points to Keith' car). Just sort of Keith's idea, put a pop bottle and have some wheels on it and just put this [rocket engine] through the middle. Make a hole and have it go much faster. You could just put the weights inside and it would still be lighter than this [holds up their "Constructs" car for me to see].
>
> **Tim:** But the only different ... thing I'd like to do now is, if I made out an extension of how to puncture the CO_2 cartridge with a very small hole. But equally, you can just have a way of tying a tubular coil here (points to the center of the car he is holding) and you can somehow just push them together and they'll pull something like this (gestures with his hands) and that will poke a hole in it and then it will shoot (gestures with hands again).

While Tim and Mark shared a desire to extend their project each talked about it in a different way. Mark wanted to explore how a new lightweight design would affect the performance of the car. Tim also wanted to improve the performance of the car but he wanted to explore it from a different perspective. His focus was on exploring new ways of puncturing the CO_2 cartridge. The class presentation of their car did not signify its completion for either Tim or Mark, at least in the action-thought sense.

In science, it is often problematic to demarcate what constitutes an "event". I suggest that a similar problem occurs in the analysis of the stream of student experience. Table 2 presents Tim and Mark's individual accounts of the events which were salient for them in their project. Each account is a compilation of some of the written responses made by each boy to a set of questions on worksheet given to all the members of the class by the teacher, Ms. B.

Table 2

Mark and Tim's individual accounts of events in their project

Compilation of Mark's written comments:

The task of our machine was for it to be able to move a load a certain distance. Our machine is a car that is powered by CO_2. And it will weigh under 700 grams without the extra weight of 200 grams.

When you told us that we could make a machine Tim and I both had the same kind of idea. He wanted to do something with a rocket launcher and I wanted to do something with a car. When we started to work together we decided on using a car that would move a load of 300 - 400 grams. But that was not a good weight for the car. So we changed it to 200 grams and we could put 100 grams on both sides. When we were making the car we had 2 simple machines already built into the car. But we needed three. We started to try and make a pulley. After many classes we found that a pulley system was not a good idea. So we decided to make a wide wedge so that the air that was going to hit the car be reflected up so that the car would be more air dynamic. After some changes our car was done. It was almost what our original design was, but much lighter. However the task did not change at all. But we did have a few ideas about how to do it different, in the end we used the first task.

When we did our first test in the hallway the car worked very well. But it did not travel straight. Then when we did it in the class it did not seem to work. I thought that when we did it in the hallway we did not have any weights in it, but Tim said that we did. I do not know why it did not work too well in the class but I think that the weight was much less in the class, then it was in the hall.

Our machine did not meet all of our specifications that we wanted it to in class, but it did in the hall. It carried a weight and it went over 20 meters. When we finished the first design it did take the impact of a fall from the table and running into a wall. So that part went good. There might have been one other reason that our car did not work in the class. That might have been because that we had to make 2 holes into the canister. The first one that was made was too small. The second was too big. This was most likely the reason that the car did not work well in class. I think that if we got Mr. T. to make the hole that the car would have moved 20 meters and it would have met all our requirements. All of the things that we wanted the car to do did not change when we were working on our car.

Compilation of Tim's written comments:

The reason my group made a car is that we like seeing things go fast or move. What I liked the most about my completed project was how much it improved over the course of the week. Our project went quite smoothly with only a few problems related to the third simple machine and the power source.

While working on the project I learned a lot about how simple machines work and where. For an example we were having trouble coming up with a third simple machine so we decided to use a pulley to meet the standard. However we had lots of problems getting it to work and we were running out of time. So the morning of the day that we were to be tested we made an inclined plane and placed it over the front of the car. This acted as an air wedge and wind shield and also made it look much more attractive. The point is we found we were able to overcome problems and learn from them as well. We made a good looking and successful car that worked three fourths of the times moving far and fast.

> **A very big help was Leo MacDonald. Almost every day we talked to him and got different ideas about how to make parts of our machine work. He gave some ideas on how to use the pulley as a guide line and also helped drill holes in our rocket tube for the engine stopper.**
>
> **We didn't really find anything unexpected about the project but it did come as a surprise to me how a CO_2 cartridge works seeing that I had never used one before. If I had the chance to do this project again I would try to make the car lighter and more streamlined. I would also like to get better wheels so it would have less resistance.**

It seems that Mark considers his engagements in the project to constitute a single event. Mark seems to consider the performance of the car (the outcome of the project) to be the event which is most salient to talk about in his account. Tim, on the other hand, seems to consider his engagements in the project to have included multiple events. His account describes events which are related to both the performance of the car and the processes used to develop the car. This seems to indicate that Mark's and Tim's experiences in doing the project and the understandings they developed were quite different. A question which is raised by this is "What counts as an experience".

Educators tend to think of learning events as bounded by the temporal and spatial confines of the school. Projects of this nature which involve significant out of school components, significant temporal extensions, and significant contextual extensions raise important issues about the nature of cognition and learning.

If an event is viewed as the outcome of a sequence of action-thought experiences then that can have important implications for the kind of conversations which are possible between a teacher and his/her students. Similarly, if an event is viewed as both an outcome and a process of developing an outcome then that opens up other conversational pathways between teacher and students. It is often the case that when a student is asked about their thinking they interpret this as an opportunity to talk about the outcomes of their thinking. On the other hand, other students consider the ways they were engaged in a project to be equally important to the outcomes of the project in their descriptions of their thinking.

How can this difference be explained? Is it the nature of the student's learning environment, is it the nature of the student, or is it the nature of the student's actions to engage their environment (i.e. the nature of the structural coupling between student and environment) which are most important to consider? Arguing from the perspective of an outside observer it would seem that the nature of their learning environment is not relevant to explaining why Tim and Mark's experiences in this project were different. It seems most plausible to suggest from this perspective that both Tim and Mark experienced the same learning environment since it was co-created by each of them. On the other hand, if one considers a more personal perspective, it would seem possible that each boy was bringing forth different worlds of significance from a shared environment.

Is it the nature of each boy which is important? Enactivism argues that individuals bring forward personal histories of structural coupling. In this sense it would seem that Tim and Mark each brought to the project a different set of agendas and backgrounds for engaging in this kind of project. This is a potential explanation for their different experiences. However, both Tim and Mark told me in my interview with them that they each had extensive experience with extended science fair projects. It would seem that is not an adequate explanation for the qualitative differences in Tim's and Mark's experiences in this project.

What about structural coupling? In this project each boy participated in different kinds of actions while they worked side by side to complete their project. Mark owned the "Constructs" (the material used to build the frame of their car) and he seemed most concerned with developing this aspect of the car. Tim's expertise was with rockets and his main concern was with the development of the car' propulsion system. However, it became apparent to Tim that an important component of the propulsion system was the geometry of the chassis. As a consequence of this it seems that Tim engaged in the building of the chassis on an equal footing with Mark but that the incorporation of the propulsion system was left mostly to Tim. In short, Tim was more fully implicated than Mark in the complete development of the car because he considered all stages of the public development of the car to be important to achieving his personal goals (i.e. launching a rocket powered device). Mark on the other hand had achieved his personal goals once the chassis for the rocket car was developed. During the sequence where they worked to incorporate rocket propulsion into the chassis of their car Mark seems to have been less implicated in the developmental process than Tim. One indication of this is that Mark seems to begin to consider it important to include Mr. T. (their shop teacher who had rocket car experience) as a collaborator in the project. Tim, on the other hand, felt that any difficulties could be addressed without appeal to any outside experts during this part of the project.

In my final interview with Tim and Mark (Keith was also present) they commented that they thought they would be able to successfully complete the written analysis of their machines because they had developed a significant understanding of their car. They described the process of understanding as being like the emergence of a kind of vision.

> **Leo:** Will you be able to do well on that [written analysis] do you think?
>
> **Tim:** Yes.
>
> **Mark:** Because we understand our project.
>
> **Keith:** Anybody could do really well on that if they know what their machine does and what types of problems they have. They can do well if they know their machine well enough.
>
> **Leo:** Tell me about this "knowing your machine" or "understanding your machine". What is it that was special about your thinking and your way of thinking in this project that allows you to know your machine and maybe someone else not to know their machine quite so well?
>
> **Keith:** Well I knew what my project was going to be from the start. I had sort of a vision shall we say, of a car not going too fast or anything, but just moving just enough to keep a five hundred gram mass going. If you have an idea right from the beginning it sort of develops as you go along and it gets embedded in your memory, like you know it off by heart from there.
>
> **Leo:** (looks toward Tim & Mark) OK, what is it that allows you guys to understand your project and will allow you guys to think that you can do pretty well on this write-up?
>
> **Mark:** We worked hard on it.
>
> **Tim:** We worked really hard in class. Like we never fooled around. I have this memorized now. I could make a drawing of this after not seeing it for a long time and I could get every joint or piece of plastic on this in the right place. I have such a good feeling for it because I know it and I also have developed knowledge of it, like how you work with CO_2 cartridges. I know why it didn't go well [in the class presentation] and I know why it did go well the first time [in an early test].

Meaning and understanding emerge when students are physically engaged in enacting their ideas. Furthermore, ideas which are physically enacted are themselves a form of understanding. Amy, Tim, Mark and Keith (and most of the other students) engaged in physical re-enactments whenever they described the workings of a machine or explained their thinking about it. This occurred both during the project and the final interviews.

How does a student consider thinking to be influenced by self-direction? Students drew sharp distinctions between self-directed engagement in science and their other activities. Tim and Mark describe this in the final interview:

Leo: Tim ... Can you compare your thinking and the way you were thinking in this project with the way you think when you 're doing other science activities?

Tim: Well, it's a bit different when you do something like this when you can actually make things. A lot of the other science activities you do we have something that we're supposed to do. We have, we read from the textbook and we have to .... see who can dissolve salt or something. **Here we can do whatever we want ... So like then I thought differently**. I didn't think from the book and think of from like a professional scientist's kind of point of view. I was thinking of what a kid would like. But also someone that maybe like a scientist wouldn't care as much about ... those little rocket powered cars. I was thinking more of people my age, of what people our age would like.

Mark: Well, when I have a project that I can choose what I'm going to do I'm usually ... usually a lot of people don't do what I'm thinking of. Last year I did for my science fair project an experiment with bean seeds and steroids and no one else did that in the school and there are other projects that were repeated by other people and I'm just doing an extension of that this year. I found that no one else had the idea of using a CO_2 cartridge or a rocket launcher or a rocket in a science project with machines.

Leo: So you feel that you have an opportunity to have some originality in a project when you think for yourself that isn't present, maybe as much, when you're doing something from a textbook or somebody else is giving you directions?

Tim & Mark: Yes.

Leo: I was interested Tim in your comments just now that you were thinking more about what someone your age would like to do and you were saying that was a little different from your other normal science activities in the textbook for instance where it's stuff that a scientist would want you to do. Can you tell me a bit more about that?

Tim: Well, it's like when we do science normally we have to do, we have to learn about different aspects of the science world. But were actually not inventing anything. Whereas here, well this didn't actually turn out all that well, but like I made a car and there's tons of little kids or people of my age that would like a car. I know our IA teacher, I found out, has made ones that are much different. They're made out of wood and they got like close to a hundred kilometers an hour. Yes. Real fast with CO_2 cartridges.

Self-directedness seems to allow for a different kind of thinking - thinking which entails inventing and creating new things - acting in the present as opposed to the future, as a young person would want to act and not necessarily as an adult might want them to act. Can experience ever be guided? Can the meanings which emerge from experiences ever be predetermined? It seems that for Amy, Keith, Tim and Mark, meaning emerges from those experiences in which they consider themselves to be fully implicated. Not only are their experiences personal constructions, they seem to be fully aware of this. Knowing and understanding are not isolated from the knower.

In this chapter I have presented and interpreted portrayals of student engagements which illustrate how three key ideas of enactivism can assist us in portraying how understanding may be enacted by students in self-directed settings. I have also looked for and presented instances where students themselves spontaneously use enactivist language and ideas in order to describe and explain their own ways of thinking and acting. These instances are intended to lend support for the viability of enactivism as a framework for making sense of thinking in science classrooms.

One aspect of this kind of thinking that warrants closer examination is the question of how the meaning of a task or a problem setting is shaped by takes shape for a person. This is the subject of Chapter 6.

Chapter 6: Shape of the Problem

Meaning is not created through individual intentions; it is mutually constituted in relations between activity systems and persons acting and has a relational character. (Chaiklin & Lave, 1993, p. 18)

To see a problem is to see something that is hidden. (Polanyi, 1983, p. 21)

This chapter will present instances that illustrate the dynamic and plastic nature of students' ways of creating meanings while engaging the worlds they bring forth as they explore task or problem settings. A verbal statement of a task or problem is not a simple matter which includes a straightforward path to its resolution. Rather, the meaning of a problem unfolds and takes shape as it is explored and enacted and may evolve in complex, unexpected and sometimes unpredictable ways. As noted in the previous chapter, what constitutes viable or adequate conduct in a problem setting solution can be diverse in nature. Multiple pathways of engagement in a problem setting are implicit in a problem schema or statement and it is the nature of a person's engagement that determines the meanings of the problem and the way those meanings take shape.

What is a problem and what qualities give it shape? Shape of a problem may be considered in a number of ways. First, the shape of a problem may be considered as an evolving process or **way of being engaged** in action-thought. Second, the shape of a problem may be considered as being **embodied in the constructions that emerge** from sequences of action-thought. One might say that there is a physical shape to the emerging constructions of students' building activities. Third, the shape of a problem may refer to the **evolving nature of an environment** in which the problem activities occur. One might also say that there is a shape to a person's engagements with the phenomena around them - i.e., there is a coemergent shape to a person's action-thought within a setting. Fourth, the shape of a problem may be a **reconstruction (and/or deconstruction) of a sequence of action-thought**, e.g. in a written report of a problem investigation. Shape may also be portrayed in a metaphoric sense. This may allow more holistic aspects of problem engagements to be developed and interpreted.

This chapter will present explorations describing the dynamic nature of shape as revealed in students' engagements with complex task settings. The four specific instances that will be presented and analyzed are selected to focus on **different patterns of engagement** that the dynamic and fluid shaping of understanding can take. I am not talking about solving problems in the conventional science classroom sense (Kuhn et al, 1988, Carey, 1989), although the emergence of what is considered a viable response to the classroom assignment will enter into the portrayals. Rather, I will attempt to portray the **recursive** and **enactive** aspects of how the process of action-thought creates an understanding (usually multifaceted) of what the problem means. I will also attempt to develop an argument that the shape of a problem is a quality that is coemergent in nature in the sense that it emerges dynamically and continuously for the persons-acting in a setting. Furthermore, the dynamic and evolving nature of the shape of a problem is a quality that is experienced by everyone acting together in a setting. In fact, it is one indicator of the viability of the person's engagements with the setting.

Bringing forth a shape in doing: A clinical study of a broad context task setting

My first entry point into thinking about the complex texture of interpretation in student investigations occurred when I read approximately 150 protocols describing the work of students engaged in the paper towels task (Erickson et al, 1991). The "paper towels investigation" (Shavelson and Baxter, 1992) has been used extensively in performance assessment studies. It is described in full in Technical Report II of the 1991 BC Science Assessment (Erickson et al, 1991).

Dan and Tristen, two eighth-grade students, visited the University of Alberta to participate in a clinical study involving materials and equipment from the paper towels task which were on loan from the B.C. science assessment. The materials and equipment provided to Dan and Tristen were more extensive than students are normally accustomed to having available during a classroom science investigation. Dan and Tristen found, laid out on a work station, one roll each of brown, pink, and white paper towels, assorted plastic funnels, graduated cylinders and beakers of different sizes, scissors, stopwatch, various types of balances, eye dropper, calculator, ruler, 30 cm x 40 cm tray, paper clips, wooden chopstick, and a waste container. I introduced Dan and Tristen to the materials and presented them with a card on which was written the following question: **Which paper towel holds the most water?** A sheet for written responses was also supplied.

Dan and Tristen chose to conduct their investigation for about 1.5 hours. The episode was videotaped and followed up with an interview that involved three segments of stimulated recall based on the just-completed videotape. In addition some strategies used by other students were demonstrated in order to provoke comments by Dan and Tristen. The following paragraphs describe the initial stages of Dan and Tristen's investigation that illustrate aspects of the shape of a dynamic process of coming to understand. It is not intended to be a chronology of their entire investigation. The complete transcript of Dan and Tristen's Paper Towels investigation is presented in Appendix C. I have highlighted verbatim excerpts of their taped discourse as an aid to the reader.

Dan and Tristen began the activity with a discussion of the equipment available. They quickly selected a subset of the available equipment. Referring to the tray, Dan says **"I think this will be major"**. One possible interpretation of this statement is that Dan and Tristen focused on aspects of the task setting (i.e. specific materials at hand) as an entry point to developing an approach to the problem. This is often the case in practical problem settings. The school approach of planning a strategy before engaging in action may be of limited value in such engagements.

A general discussion of a strategy that could be employed to measure the amount of water held by the three towels followed. Dan comments: **"... if we completely dunk the towels in the tray then we can somehow put them on the scales to find out how much they weigh."** They decide to try some rough measures **"to see if this will work"**. They try finding the weight of dry towels on the scales to see **"if it would show anything"**. This raises the question of what constitutes "progress" in a problem. Of the multiple pathways that a person can choose how is a particular pathway related to the ongoing actions and decisions?

There is a continuous running conversation about strategy as they begin trying some simple measurements (i.e. - dunking a towel, throwing it into a beaker and weighing). Dan comments to another observer (my supervisor) and myself **"So we're not actually taking results at this stage...we're just trying this to see if it's going to work."**

Dan and Tristen began the paper towels activity with an immediate hands-on manipulation of things without a noticeable period of planning. Students may prefer to begin activities with unstructured action in which the focus is placed on simply noticing and getting a feel for the phenomenon. It appears that visual evidence has a rather profound impact. A student with a holistic view of observation "notices" many different things but does not necessarily focus on any one aspect of the phenomenon. The emphasis is on getting a sense of the diversity of the phenomenon and a feel for some of the relevant connections. It is mostly an inductive enterprise in the sense that the students seek to broaden their focus.

An extensive discussion ensues and Dan and Tristen make several comments about controlling variables. In one instance, Dan comments that **"If everything else is constant then our responding variable should be accurate."** It seems as if the boys decide that since they are in a science lab being observed by science education researchers they ought to display some scientific behavior. The conversation continues:

> **Dan**: I suppose we should go with a hypothesis first.
> **Tristen**: Yeah.
> **Dan**: OK, the white paper will hold the most because it's the heaviest.

There is an interesting sequence in which Dan first notices how the towels behave as they are dunked in the tray of water. Dan places the pink towel on top of the water and suddenly becomes very excited and animated as the wetting towel quickly expands. He moves closer and looks intently at the wetting towel for a moment before stepping back and exclaiming in amazement **"Holy ... it went ...Whoop! (moving his hands apart to illustrate the expansion) .... Expando, Contracto!"** Dan now becomes even more interested in the paper towel and places it inside a beaker where he swishes it around to see if anything else unexpected might happen. Later Dan comments to Tristen that **"maybe we should think about controlling this"** (referring to the paper towel expansion). However, when they observe a similar phenomenon occurring in all the towels they decide that the "completely wet" state is more stable than the various "becoming wet" states each towel displays. The wetting action is not included as a control variable but Dan was clearly intrigued by the event, watching it happen every time he placed a paper towel in water and engaging in physical movements and verbalizations similar to those he used during his first encounter with the phenomenon.

The person-environment connection is strongly demonstrated by Dan. He looks closely at things, often repeatedly (i.e. the wetting action of the paper). This "active-noticing" is accompanied by physical action (arm spreading) and verbal embellishments ("whoop! expando-contracto") as he watches the paper towels expand. Often, in order to communicate meaning to Tristen, Dan would grab a beaker and move it back and forth from the scales to the tray, apparently rehearsing the actions required to generate an "event" before making it actual, once again enhancing his actions with various sound effects.

There is a noticeable connectedness between Dan and the paper towels in that moment of wetting that clearly had a strong impact for him. In later trials Dan would comment to Tristen just before he immersed a towel in the tray of water **"Ready?...I'm going to do this."** As if to invite Tristen to share in the experience. Tristen seemed less interested in observing the wetting action. He seemed more interested in preparing the towels for wetting by tearing sheets from the rolls and trying to remove the curl from each sheet of paper. Dan seemed unconcerned about the curl in the paper towels and waited impatiently for Tristen to prepare new ones for wetting. Although Dan was aware of Tristen's "curled paper" phenomenon and Tristen was aware of Dan's "wetting area" phenomenon each of the boys seemed to consider the phenomenon brought forth by their own actions to be most significant. Worlds of significance are created and shaped by the actions of the persons involved. These worlds are simultaneously intertwined and independent, shared and separate. Taken together, the actions of Dan and Tristen take on a shape which is more complex than their individual contributions to the enacted meanings of the problem as it takes shape and moves forward.

After conducting several wetting trials, the boys reached a point where they seemed confident that they had figured out how to go about doing their investigation. Their conversation slowed down as Tristen prepared a set of towels for dunking and Dan prepared the wetting tray. Both boys seemed more relaxed and confident at this point. Dan even took a moment to inquire with Heidi (my supervisor) and me about their progress to that point. **"How are we doing so far?"** He was clearly pleased with their progress and announced to the us: **"... We learned about the scientific method at school.....they pounded that into us to the extent that....well, I dream about it at night."**

In preparation for the scheduled session with Dan and Tristen I decided to do the paper towels investigation for myself. I did eight separate experiments. It was interesting for Heidi (who observed me during this activity) that the experiment to which I attached the most salience was the experiment which seemed least focused on the question provided by the task. This approach used a dropper to wet three separate towels near their center. What aspect of this investigation piqued my interest more than any other? It was the strong visual impact of the dynamics of the wetting phenomenon which yielded two visually pleasing aspects. The first was the motion of the wetting area as it spread outward from a source and the second was the emergence of an unexpected elliptical geometrical structure. The experience of the elliptical wetting pattern was similar to the arguments of Bohm and Peat(1987) in that it was a revelation of an implicit order which I had not imagined at the outset. This was so impressive that I immediately wanted to do it again and I found myself repeating the experiment a number of times simply to re-experience the event again. Dan seems to have noticed the wetting action of the towels several times during his engagements. Perhaps, the shape of a persons thinking can be strongly influenced by their structural coupling to the setting, the equipment at hand, and the phenomena which emerge in unexpected ways.

After Dan and Tristen had finished their investigation I shared this technique with the boys. However, they were not nearly as impressed as I. Could it be that one must have a personal physical connection to an action in order to attach real significance to it? For me, it was the unexpected nature of a wetting phenomenon that I had personally created that was most important. Dan and Tristen brought forth their own personal phenomena upon which they decided to act. Perhaps a person needs to actively bring forth and feel as if he is "living inside" a world in order for viable meanings to develop and take shape for him.

Dan and Tristen developed a sense of understanding about what to do in this investigation by recursively moving through a sequence of thought and action. It seems that the development of meaning for the boys was embodied in their actions (their connections with the paper towels and the equipment) as they progressed through the investigation. New ideas emerged from previous actions and new actions emerged from those ideas. There was a necessary connection between the boys (especially Dan) and the world around them as they developed an understanding of what they wanted to do in this investigation.

Did their earlier hypothesis act in any way to guide their actions in their investigations? To me it seemed to be an off the cuff remark, a kind of vestigial reminder of past experience in school science activity which evaporated as quickly as it emerged before Dan and Tristen returned to a physical manipulation and observation of the array of equipment and material before them. This supports Polanyi's argument for the role of tacit knowledge as the foundation of developing understanding. Polanyi(1983) claims that focusing explicitly on specific component elements of a complex process can interfere with the manifestation of understanding.

How did the boys narrow the problem? They picked out a number of potentially relevant variables. It seems as if they sort of mentally "held them up" and talked about them. They went through a whole series of variables - paper area, weight, texture, water temperature, amount of water in the soaking tray and drip time. Should the paper be completely immersed or not? Should the stacked paper towels be placed in the water with the curved side up or down? Should the beaker be dry before every measurement? How many pieces of paper should be the experimental unit? Some fairly sophisticated thinking is revealed by these questions. Tristen and Dan answered these questions based of the calibration of the measuring instrument they chose(the balance scale). Some variables were arbitrarily rejected and described as "stupid". No reason was given or required, they just decided that they didn't want to do that (a strong volitional element). Others (i.e. water temperature) were worried about out of proportion to their importance. An interesting one was their decision to dry various surfaces, considering how sloppy (i.e. water spilling, eyeballing volumes) they were in other measurements. Why would they think that this was an important action? Perhaps this has to do with the fact that the task involves paper towels (e.g. that's what paper towels are for and there were big rolls of them available).

Dan and Tristen's decision to "go with mass" rather than volume and that going with mass took care of the volume variables was not entirely correct but they quickly persuaded themselves that it was (**"It really doesn't matter"; "It's all the same"**). It seems as if this reduced the number of degrees of freedom in their system to a point where there was **under consideration** only one responding and one manipulated variable. As other possibilities occurred to Dan and Tristen they basically argued their way out of including them (e.g. uneven thickness in towel roll, curvature of the papers, water left in pan, poking the towels to wet them). Tacitly, all of these were in the picture but the "scientific part" of Dan and Tristen focused on a reduced model with clear boundaries.

Dan and Tristen tried to develop a larger explanation that would coordinate all of the bits of information they had gathered in a coherent fashion. They talked about the microscopic properties of the paper towels in relation to the macroscopic properties of the paper towels and they made predictions based on these properties. (i.e. bubbles on the pink paper would affect the water absorption rate (large scale performance of paper)). None of the protocols from the BC science assessment indicated that any of the students who did the paper towels activity constructed a linkage between microscopic properties and macroscopic observations despite the fact that many of them noticed the bubble shaped air pockets, especially on the pink towel. Perhaps the absence of an explicit time constraint for Dan and Tristen may have allowed them to engage in more sophisticated thinking or pattern recognition. According to Bohm and Peat: " Only when the intelligence operates in a free and creative fashion can the mind be free of its attachment to rigid structures of category and is then able to engage in the formation of new orders." (p 115). In the world of physics, adding constraints reduces the number of degrees of freedom. However, in the world of human cognition it seems that the opposite is the case.

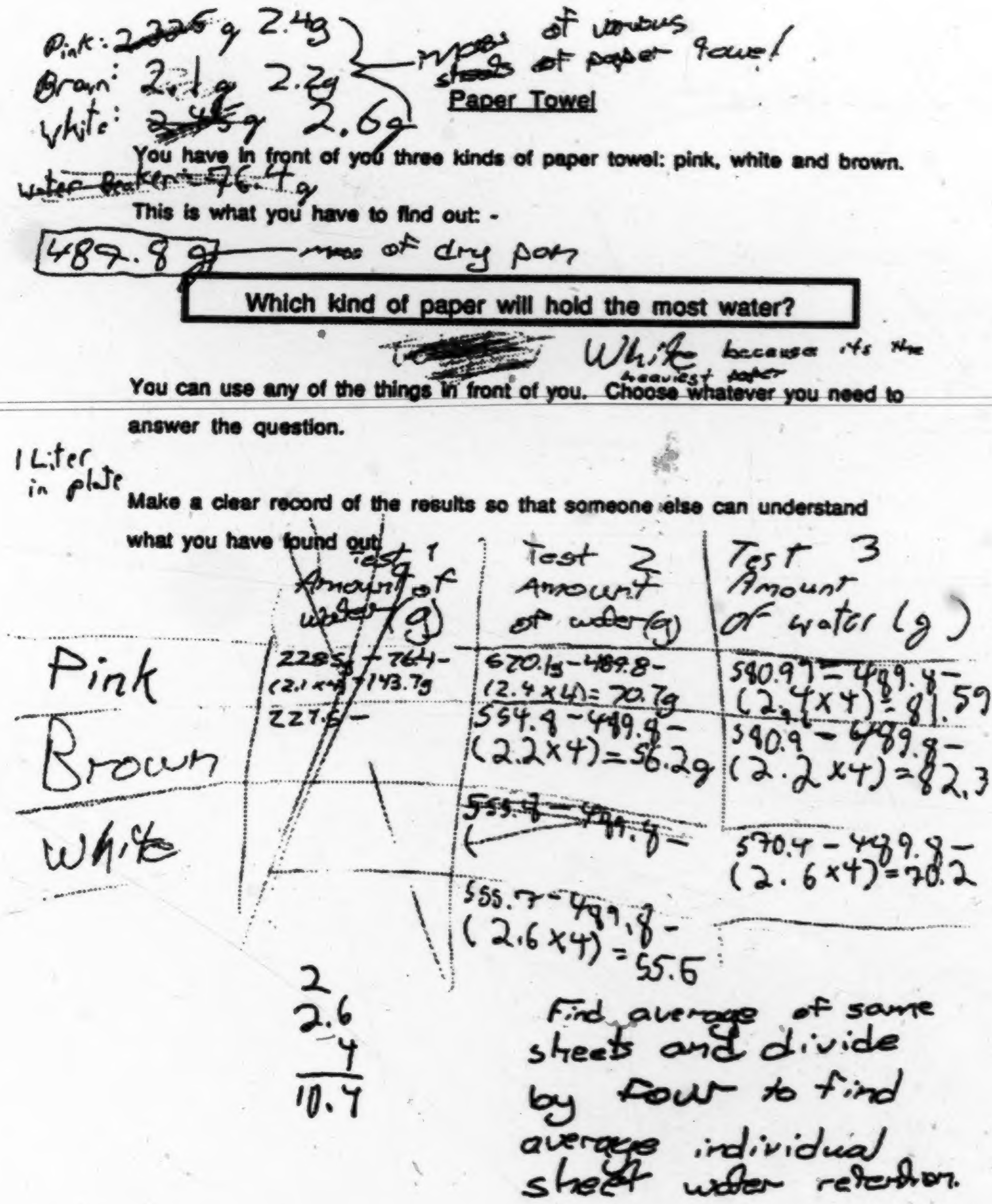
As it became apparent to the boys that their initial prediction that the white paper towel would be most absorbent (because it was the heaviest) was not going to hold up, Dan and Tristen rationalized their results with reference to the microscopic properties of the paper towels ("industrial cheapo"). I made similar speculations when I was confronted with the unexpected wetting patterns for the three paper towels. Was it the arrangement of the pattern of bubbles on the pink towel that caused it to display such a unique pattern or was the cause somehow related to an uneven distribution of fibers throughout the towels? It is gratifying to me that the boys were able to spontaneously connect "seen" macroscopic results with "unseen", yet envisaged and enacted, complexity at a microscopic level. It indicates that Dan and Tristen "extended their vision" by enacting a new world of significance from a previous one. The act of bringing forth new worlds of significance may be more important than the nature of the worlds themselves. Viability is not determined on the grounds of qualities which reside within the world of significance itself. Rather, it is the way in which the person engages a world of significance in order to generate new worlds which contributes to the viability of action-thought. Even the slippery or unstable stepping-stone may be used when crossing a stream, especially since every stone changes once it has been stepped upon.

There was a discernible ebb and flow in the hour and a half that it took Dan and Tristen to do this self-directed investigation. No time constraint was specified to them. The boys did ask, at one point, **"How much time do we have?"** and they were told that they had as much time as they needed to complete the task to their satisfaction. This opened up the possibilities in a significant way for the emergence of personal thoughts which flowed from one action to the next. The flow was not uniform or evenly paced but rather was characterized by periods of high activity interspersed with slower periods where not much seemed to be happening either in their ideas or their actions.

The ebb and flow was noticeable in the early stages of the investigation when the boys were "trying out" and "playing" with ideas about how to go about the whole thing. Once an idea appeared it generated informal actions which were carried out in the sense that they were not so concerned with answering the question as they were with creating experiences. As the investigation proceeded I sensed that they were exploring various pathways toward the final goal of finding a tenable strategy. There were many instances of doubling back before endeavoring to follow a new pathway. Nevertheless, there was a developing sense of direction and a narrowing of possibilities that were given serious consideration. A sense of emerging intentionality was also present. Dan spent a great deal of time "looking closely" at the array of materials before him, picking up equipment, studying a beaker's contents (i.e. towel and water), and similar activities that suggest an ownership of the problem that was not present in earlier stages.

Polanyi(1983) claims that "to see a problem is to see something that is hidden" (p 21). This was illustrated by Dan when he noticed all sorts of things that he had not noticed before as he played with the towels and equipment. In one sequence described earlier Dan laid a towel on the surface of the water in the tray and was amazed at what he saw! The impact of this phenomenon on Dan was much greater than it appeared to be on Tristen who, although he could see the result, was not physically involved in carrying out the action. Does understanding require a direct link between thought and action? It seems quite compelling from this account that the representationist view is not adequate to describe the interactive nature of the progression of coming to understand as revealed by Dan and Tristen.

Once Dan and Tristen decided that they had a working strategy the dynamic of the investigation changed in several ways: (1) the division of labor became more clear cut in that each now had a specific role, (2) the pace of the physical actions increased, (3) the incidence of informal chat increased dramatically, (4) Tristen became more centrally involved in the task and more assertive in his ownership of the task (voiced opinions on procedure, took initiative in recording and graphing results - see Figures 12 and 13). At this point, the development of an understanding for an investigative process and the meanings associated with it had clearly culminated for Dan and Tristen and their subsequent actions were mostly directed toward carrying out the procedure they had developed and reporting their results.



Pink: ~~2.225~~ g 2.4g
Brown: ~~2.1~~ g 2.2g
white: ~~2.45~~ g 2.6g
~~mass~~ sheets of various of paper towel

Paper Towel

You have in front of you three kinds of paper towel: pink, white and brown.

~~water Beaker: 76.4 g~~

This is what you have to find out: -

489.8 g — mass of dry pan

Which kind of paper will hold the most water?

White because its the heaviest paper

You can use any of the things in front of you. Choose whatever you need to answer the question.

1 Liter in plate

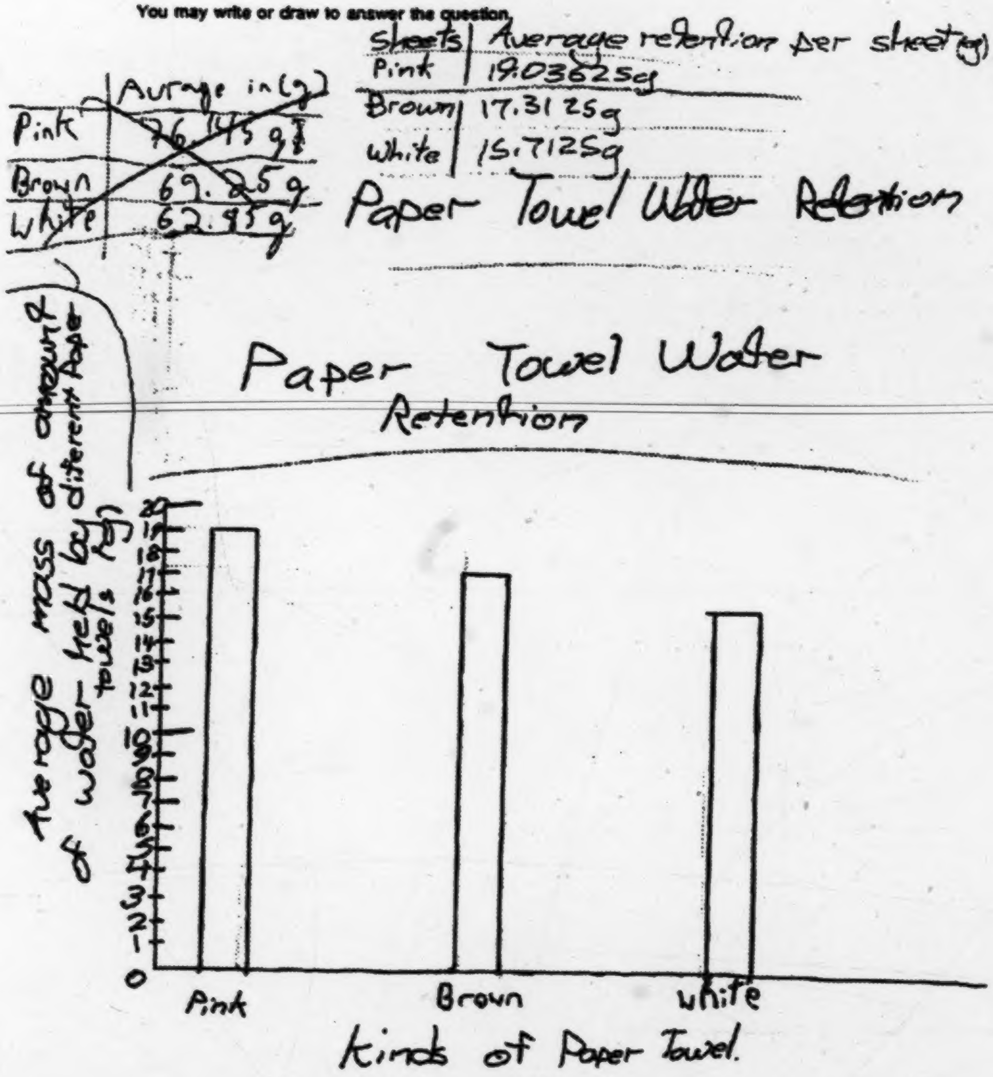
Make a clear record of the results so that someone else can understand what you have found out.

	~~Test 1 Amount of water (g)~~	Test 2 Amount of water (g)	Test 3 Amount of water (g)
Pink	~~228.5g − 76.4 − (2.1×4) = 143.7g~~	570.1g − 489.8 − (2.4×4) = 70.7g	580.9g − 489.8 − (2.4×4) = 81.5g
Brown	~~227.6 −~~	554.9 − 489.8 − (2.2×4) = 56.2g	590.9 − 489.8 − (2.2×4) = 82.3
White		~~555.8 − 489.8 − (~~ 555.7 − 489.8 − (2.6×4) = 55.5	570.4 − 489.8 − (2.6×4) = 70.2

2
2.6
4
10.4

Find average of same sheets and divide by four to find average individual sheet water retention.

Figure 12: Part I of Dan and Tristen's written work for the Paper Towels activity



You may write or draw to answer the question.

	~~Avrage in (g)~~
~~Pink~~	~~76.145 g~~
~~Brown~~	~~69.25 g~~
~~White~~	~~62.95 g~~

Sheets	Average retention per sheet (g)
Pink	19.03625g
Brown	17.3125g
White	15.7125g

Figure 13: Part II of Dan and Tristen's written work for the Paper Towels activity

Among the questions raised is the validity of the mechanistic school models of scientific investigation which concentrate almost exclusively on product. It is also important to note that generic treatments of philosophy of science and scientific method exclude the person. The position I wish to adopt here is that the process of developing understanding has a necessary unity which goes beyond the sum of its constituent parts. The jigsaw metaphor described by Einstein seems appropriate. When the pieces are connected together a resulting "picture" emerges which is more than the simple sum of the parts. The picture that is seen encompasses the personal and social history of the observer in mutual specification with the environment.

Breaking up the unity into its constituents may interfere with its existence. Even reintegrating the parts (as in the process approach to science) may not be sufficient to recreate the unity because according to Polanyi (1983) one tends to lose the tacit part of the understanding. Dan and Tristen's initial attempt to explain what they were doing in terms of what they usually did in school did not seem to work for them. They quickly abandoned this approach and turned to more informal and spontaneous action. They began to look to what was possible rather than to what was prescribed.

The action-discourse demonstrated by the boys can be interpreted from either a representationist perspective or from an enactive, embodied perspective. This is interesting because what the boys said they were doing did not always correspond to what they were actually observed to be doing as they carried out their investigation. However uncharacteristic what the boys said they did was with Maturana and Varela's (1987) enactivist view of understanding, what the boys actually did seems to have strong characteristics associated with an enactive or embodied view.

There were a number of specific indicators of an implicit enactive world view embodied in their actions. The boys seemed determined to physically rehearse their actions by demonstrating them to each other rather than describing them verbally or more abstractly. For instance, Dan repeatedly engaged in a series of animated movements of beakers and paper towel pieces as he tried to communicate to Tristen, and to himself, what would be a reasonable approach. As he did this he was also verbalizing his actions: **"We could do this and then this and then this..."**. The connected series of evocative motions and verbalizations was continually evolving as the investigation and Dan and Tristen's interactions with it continued. In other words, the generative representation of what they were doing and going to do continued to be re-presented as a workable strategy began to co-emerge with their actions. The discourse also frequently shifted toward connections between the present activity and a science fair project they were developing. In contrast, when the boys offered verbal explanations of what they were doing they tended to use a vocabulary and world view of a representationist paradigm. This is not surprising given their obvious and understandable connection of this activity with school based investigations. However, the discourse used by the boys when they were simply "talking" to each other or to themselves (either vocally or physically) was enactive and embodied in nature.

I also had an end-in-view when I tried the paper towels investigation. I wanted to find **the answer**. I began by conducting a series of rather unconnected separate investigations in which I was trying to recreate situations I had read about in my investigation of the BC assessment. As I brought forth more phenomena of significance, it occurred to me that "Hey...maybe there's more than one answer...maybe there is something to be learned in doing this activity." From that point forward I began to search for connections between the various units I had previously been treating as discrete entities. I was asking questions to myself about "Why if I do it this way do I get one result and if I do it that way I get a different result?" This was actually a very exciting result for me...more exciting than simply arriving at any single answer. In fact this experience helped me to bring forth a deeper self-understanding of how entrenched the representationist world view can be and how easy it is to fall into the trap of assuming that the world contains correct interpretations "out there" which have an existence independent of the observer.

The paper towels activity, as an educational activity, is quite unique in that the answer one obtains is dependent not only on how one interprets the question but also on how one chooses to wet the towels. In my own explorations with the paper towels, I noticed that if the towels are wetted slowly one can obtain a different result than if the towels are wetted quickly. Dan and Tristen began this activity with a view that there was a clear answer to the question "Which towel holds the most water?" and that it was their task to figure out how to get to it. This world view is indicative of a representationist position in which a single fixed point of reference in an objective world can be said to exist. By the end of the activity the boys had constructed a graph of the water holding capacity for each towel and it was apparent that they considered this to be the answer. As noted earlier, I showed the boys some alternate strategies after the paper towels investigation had been completed. I described them as "things that other kids had tried when they did this activity." Dan and Tristen were mildly interested in the processes which other students had employed but did not consider them relevant to their own answer to the question. Their descriptions of what they were doing seem to be fairly well entrenched in a representationist position in the sense that they didn't see themselves as bringing forth a world. They viewed themselves as revealing an answer which exists.

Shape of the problem and pedagogy

The shape of action-thought is a quality which is often noticed by teachers who engage students as they work in practical settings. Some students seem to prefer a brief, direct interaction while others opt for a slower, longer engagement. Clearly, the length of the school period is also a factor.

In constructivist approaches we tend to separate the problem from the actions which accompany it. In so doing we often reconstruct the problem for students in our attempts to focus on the problem we have identified. This is often quite different from the problem at hand for the student. For example, a student who describes an idea they are building may reveal some misconception in their description to the teacher. The constructivist oriented teacher will usually respond to the student with a series of questions or suggestions designed to expose that misconception. Students are often aware of this kind of strategic teacher response and realize that something must be wrong with some aspect of their thinking and may abandon the idea altogether.

Students have told me how they notice their teacher's attempts to respond to their requests for help follow a roundabout pathway to the question at hand. Other less-involved students seem to use these kinds of engagements in order to have the teacher select for them the problem which they should consider important. In the former case it seems to me that there is a danger that the student will lose track of what they were doing. In the latter there is a danger that students will never get on track. By focusing on the problem in terms of viability of existing knowledge i.e. of curricular knowledge the constructivist approach is often interpreted by a student as having a goal oriented agenda. Students not only interpret what we say and do, they also interpret our purposes for saying and doing them.

I believe that students' thinking is not as viable when they attempt to follow another persons action-thought pathway as opposed to when they create their own (this assumes the student can or wants to create his/her own). An enactivist approach focuses on the viability of a sequence of action-thought as opposed to the viability of the knowledge embodied in a sequence of action-thought. In this way an enactivist approach focuses on "what we are doing now" as opposed to "where we are" or "where we are going" and in so doing encourages the student to continue generating his/her own action-thought progressions as opposed to waiting for "acceptable" ones to emerge. This separates the degree of involvement of a teacher with his/her students from the quality or viability of their knowledge. In constructivism we generally value an approach in which students move toward a goal of minimum dependency on the participation of a teacher in their thinking. In other words we hope all our students achieve maximum independence and self-directedness. In an enactivist approach it does not matter so much how this aspect of a students' thinking evolves. In fact we encourage self-directedness to progress in both directions simultaneously. We may find ourselves becoming more and more involved in some students thinking and less and less engaged in others. In some cases we may find ourselves recursively entering and withdrawing from a student's action setting. All of these sorts of engagements can be viable. The viability of these engagements is assessed not by the particular direction in which they evolve but by the number and quality of the possibilities for continued action which emerge from these engagements. Students engaged in viable action-thought will generally not consider themselves to be completely finished an activity. They will usually want to show or us about what they would like to do next if they were to continue. My portrayals, however multi-perspective, are still "snapshots" in the students world.

Tony: Inventing an idea by shaping the possible into the actual

In a class worksheet that was part of the **Inventing a Machine** project Ms. B. asked her students to describe aspects of the project they found easy and/or difficult to accomplish. On his worksheet, Tony wrote the somewhat paradoxical statement: **"I found easy the planning of my machine and I found difficult finding an idea and building the machine."** His written response illustrates aspects of the shape of his engagements in the Inventing a Machine project. It also helps to identify elements of the project on which Tony considered himself to be developing (i.e. giving shape to) an emerging process for action-thought.

How can a researcher ascribe a shape to a process? Identifying, interpreting and describing a shape to another person's "way of engaging" their world requires a researcher to be situated in such a way that he/she has access to aspects of the other person's thinking at macroscopic and microscopic levels. In other words, the researcher needs to be able to experience and re-experience elements of action-thought as it occurs from multiple perspectives (i.e. active participant, observer, peripheral enactor). Each of these perspectives allows the researcher to develop a sense for the emerging shape of the action-thought. Furthermore, each of these perspectives is a natural part of a researcher's experience in a high activity, hands-on science classroom environment.

What is it that gives a process its shape anyway? Is it the microscopic details of the process which are most relevant or is a macroscopic perspective more helpful? I believe that both levels are useful. One seeks to get a sense of general patterns of action-thought progressions as well as entering into the process itself. In so doing, one begins to notice details which generate a holistic awareness of the dynamics of the process.

Ms. B's classroom had a pair of small storage rooms attached which held a wide assortment of materials and equipment. Various materials from agar to wax and equipment from clamps to ring stands were stored in the shelves and bins which dominated this room. This in itself is not so unusual. What was more unusual was the way Ms. B. chose to allow her students to use this space. All students had access to these rooms in order to search for materials, equipment or ideas throughout the project. Nearly every student used these rooms extensively. It seems as if these rooms became a resource to facilitate carrying out ideas but also a resource to getting new ideas. The storage room area was an **affordance** to the thinking of many students in the sense that they seemed to use it as a space for creating tentative ideas. This room seemed to become a kind of extension to the thinking of students. Most of them seemed to need to be inside the room in order to take advantage of the possibilities this room offered them. Tony chose to work at a table next to the materials and equipment room. It was an important resource for him because Tony was one of the few students who used only materials found inside the classroom. I will now describe how Tony shaped the possible into the actual.

At first glance Tony looked like most of the other boys in the classroom. He was bright and articulate and had a quick, winning smile that I found endearing. Tony was shy. Perhaps this could be explained by the fact that he was a new Canadian who had recently emigrated from Bulgaria (in my interview with Tony he indicated that he had been in Canada to that point for approximately eight months and commented on the similarities and differences between his classroom experiences there and here) or that he was relatively new to this classroom. Although Tony was not completely fluent in English he had no trouble expressing himself clearly and I never got the feeling that he was uncomfortable about trying to express or explain his ideas to me.

About a week before the project began, Ms. B. asked her grade eight students to begin thinking about the design and materials for a machine they could build. It became apparent early that Tony was one of the few students who had given the machine project extensive thought before the project began. In fact, he was the only one who made a detailed drawing of his machine early in the process of working on it. Tony's drawing (see Figure 14) resembled an engineers blueprint and at the bottom it was labeled "Tony and Company". Tony's Father was a professional engineer. Perhaps Tony wanted to emulate his Father's work.

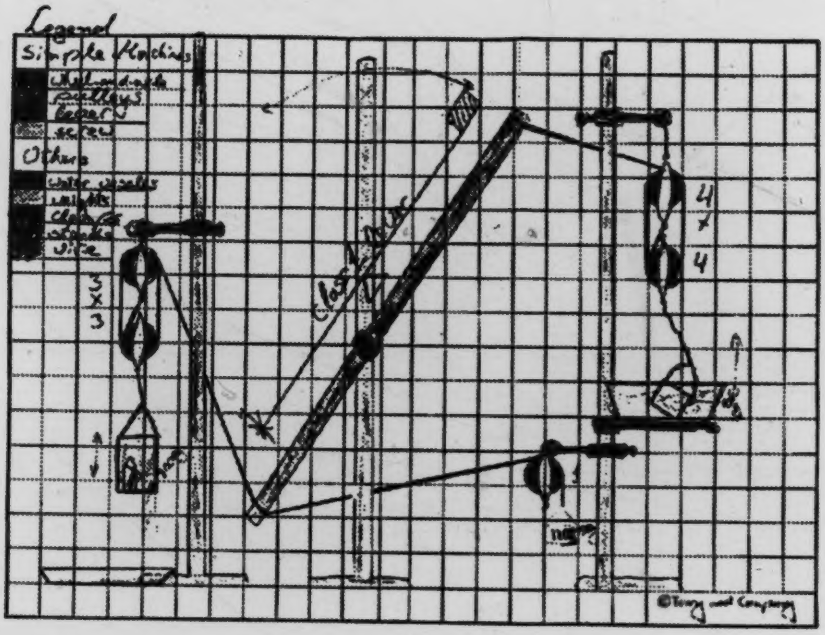


Figure 14: Tony's initial plan for his machine

On the first day of the project, Tony visited the storeroom, the trays of equipment Ms. B. had set out, and the tools/materials table I set up for equipment he could use. There was a wide variety of pulleys, clamps, retort stands, and weights available in the storeroom and in the trays. I provided various tools (i.e. hand saw, miter box, power drill, hammer, nails, and string) and some wood materials (e.g. wooden doweling of various diameters). It seemed to me that Tony was searching the storeroom for pieces of equipment that had specific properties or a specific "feel" as he took them in hand. Each item seemed to be selected on how freely it moved and how sturdy it was.

Tony began by gathering retort stands, clamps, and pulleys at his work table. He seemed to be most interested in two items in particular, a pair of four-wheel pulleys. When I first visited him at his work table he was concentrating intently on trying to arrange the pulleys so that a small mass (500 g) could be lifted. He seemed to be having difficulty balancing everything at once. The weight would periodically shift or fall off its hook and the resulting disturbance would jar the string out of the grooves in the pulley wheels (see Figure 14). This was a two person job requiring one person to hold the two pulleys and/or the weight while the other re-threaded the string through the pulley wheels. Tony smiled as he accepted my offer to help. As we worked together rigging the pulleys it became apparent to me that Tony intended to replay his actions with the pulleys several times. Each time he seemed to notice something different. Each time he seemed to strengthen a vision of how things could move in the complex system that was emerging. Recall that Dan seemed to do the same thing during the Paper towels investigation. This kind of action is similar to Piaget's notion of repetition or circular action as a way of internalizing (enacting) meanings or concepts Piaget(1963).

After Tony and I had finished working with the pulley, he showed me another piece of equipment that he had selected. It was a double clamp that allowed a kind of motion that intrigued Tony, it rotated. More specifically, one "grasping end" of the clamp moved independently of the other. I am not sure if Tony had ever used this sort of clamp before (I suspect he must have because it is a device that is often used in other activities). In any event, it seemed that a new significance emerged for Tony as he noticed how the clamp could move. He was not sure how he would use the rotating clamp, he just knew that he wanted to use it. At that point, an idea occurred to me and I suggested to Tony that a length of wooden doweling could swing freely if it was connected to one of the "grasps" on the rotating clamp. I told Tony that I wasn't sure if this idea would work but that it might be worth trying. I left Tony to work on his own and a short time later he asked me to help him use the saw and miter box to cut a piece of doweling to the length he wanted. By the end of class Tony had mounted a length (approximately 70 cm) of wooden doweling on a retort stand so that it could rotate freely through 360 degrees.

Tony's physical explorations with materials and equipment must have had an impact on his thinking about the Invent a Machine project. The following day Tony returned with a detailed drawing (shown in Figure 14 above) he had drawn at home. It included and extended many of the ideas he had explored the previous class. The drawing included the swinging length of doweling and three pulley systems which were connected together into a coordinated system. Perhaps Tony's physical manipulations allowed him to extend his affordance space for action-thought and helped him to visualize how he could integrate separate parts of his machine into a coordinated system. In addition, Tony seems to have been aware of the effective nature of his way of thinking. At the end of class on the second day of the project I asked Tony what he liked about the project. Tony smiled at me broadly and said **"I like everything about this project."**

Tony seems to have been thinking about his compound machine in a broad connected sense. Each piece seems to have been intended to be more than just a simple machine, each subsystem was also seen as a linkage to another subsystem. In short, Tony seems to have been striving to build a machine where all the parts remained connected and in motion as the machine was operated.

Tony describes his machine and its specifications as follows:

> **Tony:** The tasks my machine preformed (sic) were two - first to lower an empty can into a small pool and secont (sic) to lift the can full with water. My oreginal (sic) idea was a machine for sorting different types of balls but it required too much materials. My machine worked pretty well. The lever got stuck between the wheels of the cart (see second diagram ...) so I had to reconstruct the machine, the two cans got soft from the water.
>
> The wire had to be strong enough. The pulleys had to decrease the effort force by at least 1/3. The lever had to be very mobile.

Tony's process of engaging a world may be described as a process of constructing a world of significance. Tony's world of significance took shape in the actions he used to engage it and bring it about. He seemed to enjoy adding complexity to his world of significance while maintaining a clear understanding of the overall structure of his machine throughout the project. His goal did not appear to be to recreate an existing machine such as a car or an elevator. Rather, he seemed intent on physically exploring the dynamics of each piece of his machine as he added it, first in isolation and then in concert with the other pieces. For instance, the way the rotating doweling, which emerged as a centerpiece of Tony's machine, was incorporated in the operation of his machine continued to evolve over time. The task Tony's machine was intended to accomplish also seemed to have a plastic quality as the machine evolved over the course of the project. Near the beginning of the project he talked about lifting and lowering water and then later he seemed to attributing elevator like purposes to the motion of his machine. By the end of the project Tony had still not clearly identified a clear purpose for the motion of his machine. It appears that for Tony assigning a purpose to the motion he was creating was of little or no interest. For Tony, creating and shaping the motion of his evolving machine was a salient purpose in itself.

It was clear to me that Tony liked to put things together and take things apart. Tony's machines appear to have been a kind of celebration of materials, design and building. It seems as if he wanted to include elements of everything he had learned during the energy and machines unit into his design. Figure 15 depicts Tony's final design.

Tony worked carefully, methodically and diligently on every aspect of his machine until it was time for the project to end. It seemed as if Tony would have enthusiastically continued developing his machine if more time had been available. As Tony continued to develop the design shown in Figure 14 he discovered that the device was rather unstable, especially in the section containing the rotating wooden doweling which had string attached at both ends. Rather than abandon this component, Tony worked to improve its stability. He did this by incorporating new materials and modifying or adding complexity to existing ones. For instance, a metal dynamics cart and ramp added stability to the linkage between the two pulley systems and provoked a modification in the design of one end of the wooden doweling (i.e. a wooden knob was added to push the dynamics cart). The motivation for replacing a two wheel pulley system with a three wheel system seemed to be just for the fun of exploring a new and more complex component. By the end of the project Tony had become very adept at using all of the equipment, especially setting up the pulleys. Perhaps it was his increased capability to handle and manipulate the equipment that provoked him to incorporate the more complex pulley in his final design.

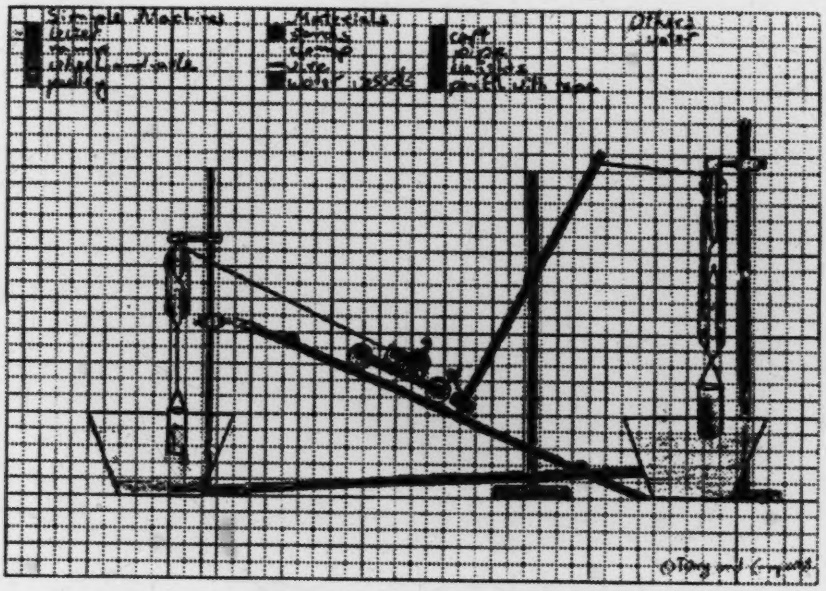


Figure 15: Tony's final design

Although Tony was shy and it was clear that he preferred to work alone, he welcomed me into his workspace as an active participant. In fact, after the first day, Tony would often seek me out in the classroom for assistance with building some aspect of his machine. One possible explanation for this may be the fact that he seemed intent on maintaining physical contact with the materials and equipment around him. Perhaps this is partly a consequence of the nature of the design of Tony's machine. It had a lot of moving parts and sometimes even four hands were hardly enough to maintain the machine's stability and make adjustments at the same time.

Tony seemed to choose materials for his machine based on how interesting he found them. For instance, the metal dynamics cart offered a possibility for motion which appealed to Tony. The pulleys offered a complexity of connections and motions which Tony felt compelled to include. It seems that as soon as Tony discovered a new possibility for motion he wanted to try to make it happen. For instance, Tony discovered that one of the clamps could swivel and hold onto an object when it was mounted on a stand. Tony played with this motion for a while before asking me if he could use one of the wooden dowels I had brought along. A first class level assembly which became a central component of Tony's machine emerged out of this innovation. It seems that Tony was noticing materials that offered new motion and structural possibilities. Once Tony selected something he would explore as many possibilities as he could discover for the motion of a particular device.

A plan emerged out of this recursive process of free exploration. After Tony had taken a couple of days to experiment with various materials and pieces of equipment He constructed a detailed drawing (see Figure 15) of a machine. His drawing incorporated all of the equipment and materials he had been using and added a couple of new components. Tony's understanding of what he would do emerged out of recursive actions in the classroom with the materials he found there. On the worksheet assignment Tony wrote:

> **Tony:** I encounter limitations of time and materials. I found easy the planning of my machine and I found difficult finding an idea and building the machine ... when I used a lever and a cart (see second diagram), it did not worked (sic) because the lever got stuck between the axle of the cart and the cart. [If I could do this project again] I would make my machine more simple ... [and] I would do my planning process faster.

Tony seemed oblivious to the noise and commotion of the other students working nearby. It was apparent that Tony was not an insider in the social structure of Ms. B's grade eight science classroom. He would usually sit by himself on the perimeter of the classroom and did not participate in the joking and wisecracking that most other students shared.

However oblivious Tony seemed to be with regard to the work of other students, it appears that some of his classmates began to notice and pay attention to Tony's emerging construction as the project proceeded. Toward the end of the project, Brian, one of the most popular students in the class approached Tony and initiated a discussion about Tony's unique system of pulleys. Brian's project also included a pulleys system and he was intrigued with Tony's design. I noticed that their collaborations continued and that Brian would from time to time leave his own construction and help Tony. As the project drew to a close, I decided to interview Tony and Brian together, partly because I thought they were close friends. During that interview Brian and Tony explained that until this project they had not really talked much. Brian openly expressed his admiration of Tony's work and commented that he considered it to be more complex than his own projects which included pulley systems from a plastic modular construction set. Tony's confidence and position in the social stature in the classroom seem to have improved significantly by this point. In my visits to the school to conduct interviews with students after the building phase of the project had been completed I noticed that Tony was sitting nearer the center of the classroom rather than on its perimeter. In the reflections worksheet he wrote:

> **Tony:** The strength I afirm (sic) while doing this project was that I like to build machines. I like my idea and I like that I planned and constructed it by myselve (sic). I met them [my goals] very good. [Leo] helped me a lot with the planning and building of my machine.

There is another level of understanding which seems relevant here. Tony (and others) brought forth an understanding not only of what they could do but also of how they would do it. Actually building something is a qualitatively different experience from deciding what it will look like. This arises not only from the challenges related to using limited materials and equipment, it emerges from the experience and pleasure of giving ideas physical shape, something that influence the shape of Tony's engagements. I will explore these issues in more detail in Chapter 7.

There was an explicit recursive aspect to the shape of Tony's approach to building his machine. Each time he incorporated a new element (i.e. pulley and weight, rotating clamp, ramp) into his construction he would re-play the motion of the element in isolation and then in coordination with the whole machine. The effect of this approach was that Tony re-played the motion of his machine many times as it grew in complexity over the course of its development.

Tony's recursive re-experiencing may have helped him to remain "in touch" with the overall shape of his design while exploring several adjustments to the design of his machine. The continuous process of freely exploring design changes and new materials meant that shape of his design was never fully determined. What was constant was his way of acting to bring forth a world of significance. In fact, the world he was creating seemed to grow in significance for him as he discovered new ways to bring forth added complexity and increased opportunities for action-thought.

The enactivist mechanisms of **embodiment** and **recursion** are clearly appropriate in describing Tony's approach to shaping his affordance space and developing understanding. However, I think there is another area that was essential in the development of the shape of the problem for Tony. This area involves an interaction between the mechanisms of embodiment and recursive engagement. For Tony, there seems to have been a connection between imbedded exploration and the larger problem in the sense that it is the larger problem which induces these smaller explorations but it is the smaller explorations that enframe the larger problem by giving it shape and ontological meaning for the learner. What is the inside of the problem turns around and becomes the frame of the problem. The shape of the problem and the problem itself are plastic entities in a coemergent relationship. This effect of this relationship is, in effect, that a learner can recursively turn the problem inside out in the development of his/her understanding. Embodiment and recursion may both be necessary components of effective action-thought in order for this to occur. Providing an environment in which a learner can employ both of these mechanisms may be essential to the emergence of adequate conduct and an understanding of the process one uses to develop understanding.

Dave and Johnny: Two boys who lost track of their problem

Once established the shape of the problem is not without vulnerability to various changes. It is metaphorically a dynamic shape with changes that can wax and wane in visibility. The shape of a problem is embodied within students ways of engaging their environment. As such it has an emotional dimension. This dimension is sometimes what is most compelling for a researcher to notice about the shape of a student's engagements with a problem setting. If "shape" is strongly embodied then it seems plausible to associate changes in the nature of a persons emotional coupling to a problem setting with changes in the "shape" of the problem. What happens when a student loses touch with the shape of the problem? Dave and Johnny, who worked together on the eighth grade **Invent a Machine** project, seem to have experienced a sequence of what they considered "successes" and "failures" during the development of their machine. How did the experiences of making "failure" and actualizing "success" change the shape of the problem for Dave and Johnny? In short, how does the "what we can do now" emerge from the "what we have done" and "what we are doing"?

"We are going to build a car that will carry a load" Dave told the class when his teacher, Ms. B, asked students to describe their idea for a machine. Dave owned a fairly complete set of plastic "LEGO" style building materials and he and Johnny decided to use it as their primary construction material. Dave and Johnny each wanted to build something that would move independently and could transport a heavy weight over a long distance.

My first conversation with Dave and Johnny occurred at their work table on the first day of the project. I was curious to see and touch the various LEGO pieces that Dave and Johnny had spread out on the table in front of them. They were only too happy to show me the equipment and snapped together various pieces in order to demonstrate how they might be used to build a car. Dave explained to me that he already knew how to build a chassis with wheels but that he now wanted to use a motor to power his car. He also talked about using the gearing mechanisms that were included with the LEGO set. He had not really used these parts of his LEGO before and seemed interested in extending his experience with these pieces of his LEGO set.

The desire to put objects into motion seems to be a strong and compelling force which influences the shape of the thinking of many students. Perhaps one experiences a sense of exhilaration through extending one's influence. A student may feel connected to the moving car in spite of the fact that it moves independently of the builder. This experience is more profound than just ownership or satisfaction. The experience of having one's thinking emerge into physical shape and movement is important. Piaget suggests that an organism naturally seeks to extend its influence in an environment. Similarly, Johnson suggests that we metaphorically project aspects of ourselves into a setting, an reverse process similar to Polanyi's "indwelling" in which parts of a setting become part of the person.

Later, Dave and Johnny invited me to see their idea. They had used their LEGO pieces to build a small car. It had a rectangular shaped car chassis and four wheels. They wanted to know if I could help them make it go. They had already seen me give other students motors and batteries and they told me that they thought that this would be a good way to proceed. I agreed and showed them a technique another student was using to make a wheel go around. It involved mounting a wooden wheel on the axle of a hobby motor which I had provided. I suggested that if they could figure out a way to mount one of their geared wheels onto a hobby motor then they might be able to power their car. The boys said they thought they could do something and went to work on it. Dave's LEGO set included a variety of geared wheels which could be arranged in many different ways. The boys took one of the geared wheels and inserted it onto the back axle of their car so that the back axle essentially had a third wheel inserted between the two wheels which contacted the ground. They mounted a hobby motor with a small gear mounted on its axle and used a LEGO chain to connect the motor to the rear axle gearing system. When the boys tested it on the floor their car accelerated dramatically and they admired their work with pride and excitement. Other students stopped to watch Dave and Johnny as they gave an impromptu performance. At about this time the period ended and the boys left in high spirits.

The development of a problem involves aspects of both problem articulation and problem management. Problem articulation depends on the "end-in-view" or the sense of direction that emerges. For Dave and Johnny this became a difficulty as the account of their activities over the next few days will show. Their "end-in-view" on the first day was to construct a machine that could carry a load a long distance. After their initial success it seems that they were convinced that they had already accomplished the most important parts of the task they had set for themselves and their attention shifted towards new tasks or "ends-in-view".

On the second day the boys decided that they wanted to make their car go faster. Why did they suddenly shift their attention away from carrying a weight toward going fast and far? I think that there are two likely explanations for this. First, when the boys tested their car at the end of the first day they noticed how the car moved. It may be that the physical experience of watching the car motion caused them to re-enact a new faster motion in their minds eye. Second, each time Dave and Johnny would pick up their car the wheels would spin rapidly in air and they would look at each other in anticipation of the outcome when they placed their car on the floor. They noticed that the car did not go as fast on the floor as the spinning wheels suggested it would. Furthermore, after using the car in several tests they noticed that the wheels did not spin as fast in air and the performance of their car was reduced as the battery power was reduced. The following question seems to have emerged from these experiences. "If a reduction in battery power leads to a reduction in the performance of the car then what about an increase in battery power?" The boys requested my input into addressing the question of how to increase the battery power in order to increase the speed of the car. I showed them how they could accomplish this and the boys were soon staring at each other in amazement at the speed of the spinning wheels.

With this success the boys began to address another problem. The connecting chain would often slip off the gear on the hobby motor. This motivated Dave to invent some new gearing designs which did not include a chain linkage. The car became heavier and more complex. Eventually they had a car which incorporated a gearing system which provided a noticeably smoother linkage between the motor and the rear wheels. Dave and

Johnny would proudly spin it with their fingers in order to demonstrate to me how much better this system worked. Unfortunately the 1.5 volt battery was not powerful enough to drive the new gearing system even when it was overpowered with more than one battery. This event shifted the focus of attention away from the batteries and towards the motor. The boys correctly identified it as being not powerful enough for their car design and inquired with me about alternative solutions. I told them that I did have a 9 volt hobby motor which they could use and gave it to them to try. A new problem emerged immediately. The new motor did not have a pre-built gear mounted onto its axle. The axle was just a bare shaft. I suggested to the boys that they try to figure out a way to mount a gear from the LEGO set onto the new motor. Dave spent the rest of the class working on this and by the end of class they managed to hot glue a small LEGO gear onto the shaft of the 9 volt motor.

Everything seemed to be progressing fairly well except that the boys began to drift apart. Dave owned the LEGO equipment and seemed intent on being the one who would be primarily responsible for implementing design changes which involved the LEGO pieces. Johnny spent a good deal of time visiting other peoples projects while he waited for Dave to finish some task. Johnny would always return and be eager to contribute when I joined the team but the spirit of cooperation seemed to disappear when I left them alone. Dave was intent on working with his LEGO and Johnny was intent in discovering what other people were doing.

Eventually Dave managed to mount a gear on the nine volt motor and incorporate it into complex gearing system he had developed. The new design was still a disappointment. When the two boys tested this new device the car would only move a short distance and very slowly at that. Instead of building a car that would carry a load far and fast they had built a car that could not carry any load and only traveled near and slow.

A good deal of bickering and sniping began to break out as Dave and Johnny could not agree on how to proceed. Dave seemed to resent Johnny for leaving him alone to build and Johnny seemed resent Dave for not allowing him to manipulate the LEGO pieces to the extent that he desired. It seems that each boy became progressively more disembodied from the construction process as the project continued. By the end of the week they were spending a good portion of their time unhappily putting some pieces together and tearing other pieces apart. Their actions seemed to be somewhat random without any sense of purpose or direction. The boys were getting close to giving up.

On the day before the presentation the boys met with me during the school lunch break. They were completely demoralized and I chose not to record any of our conversation. They had been unsuccessful in getting their car to move in the way they wanted. They seemed incapable of recapturing the original version which had been so successful or reshaping their existing design into something similar. It was obvious to me that the car they built had become too heavy and that their gearing system had too much inertia for the hobby motor to power it. For a moment I thought that I should just rebuild their car in its original design for the boys, but I quickly decided against that approach. My concern was not that I might be doing too much manipulation (in fact we did try some minor modifications that did not work). Rather, my concern had to do with for whom the new construction was intended. It was clear that they did not consider that design viable so there was not much point in me trying to make it into something it was not. I told the boys that I was also unsure about how to proceed but if they showed me what their machine could do in its present form then maybe some ideas would occur to us. I was trying to encourage the boys to think about what could be done rather than on what could not be done. Dave demonstrated the car. It slowly moved a short distance (30 cm) on the table. Dave looked at me, shrugged his shoulders and mumbled something about how they didn't even have enough simple machines in their design. Johnny who was sitting nearby seemed a bit more interested now. His interest in other peoples' projects paid off as he suddenly announced "I know how we can include another machine" and proceeded to describe an idea he got from another project. It involved installing a ramp on top of the car sloping toward and extending over the front wheels (see Figures 16 and 17).

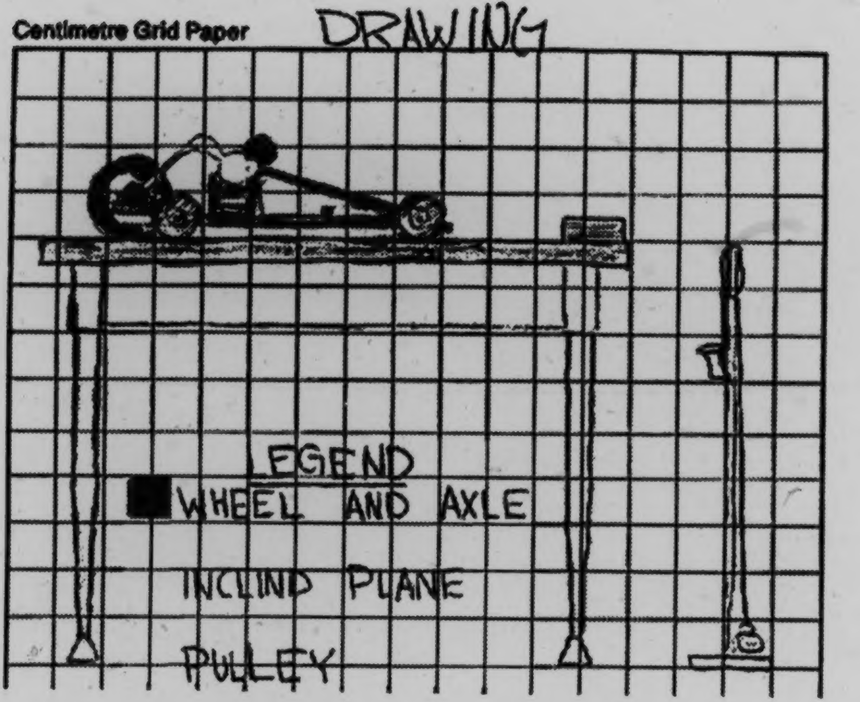

Centimetre Grid Paper
DRAWING
LEGEND
■ WHEEL AND AXLE
INCLIND PLANE
PULLEY

Figure 16: Dave's and Johnny's machine

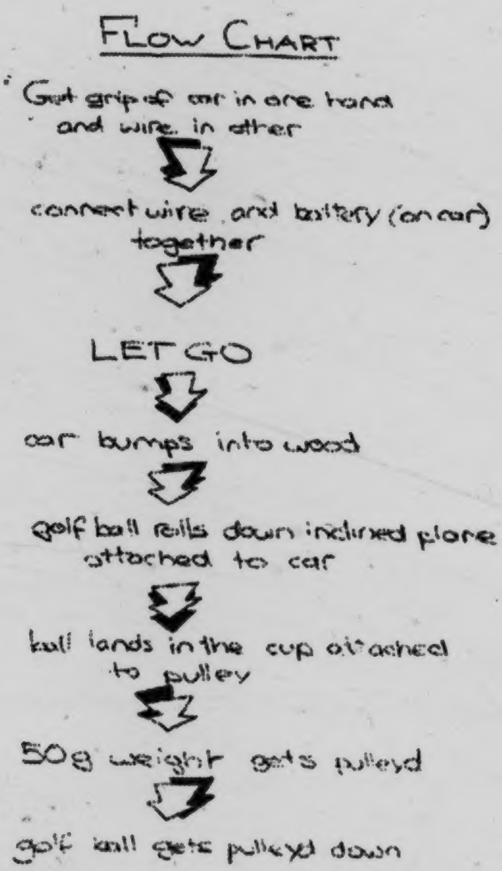
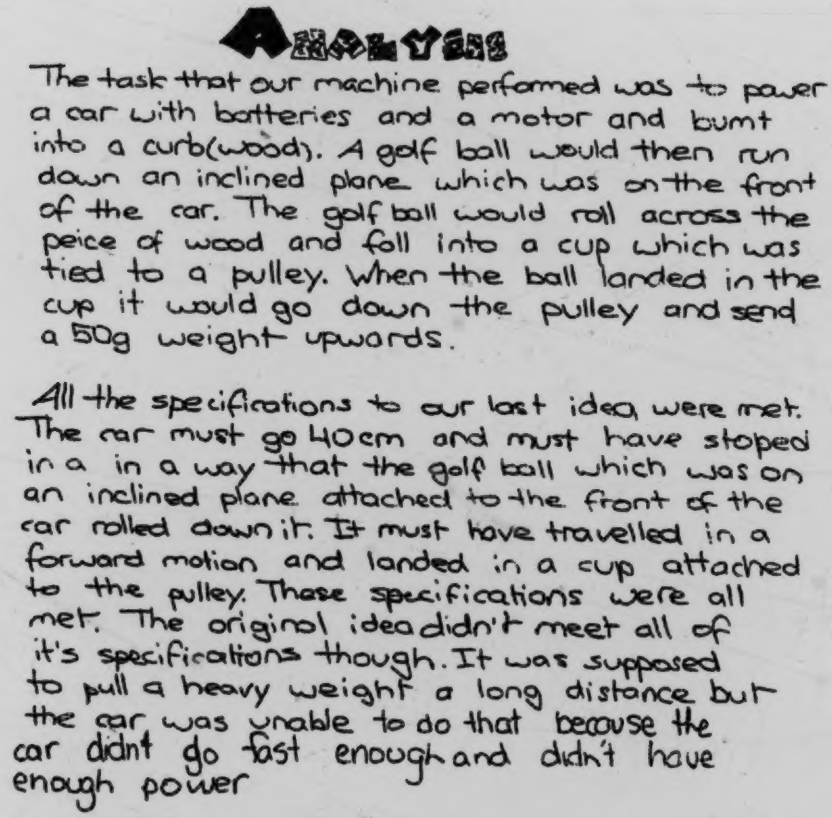

FLOW CHART
Get grip of car in one hand and wire in other
connect wire and battery (on car) together
LET GO
car bumps into wood
golf ball rolls down inclined plane attached to car
ball lands in the cup attached to pulley
50g weight gets pulleyd
golf ball gets pulleyd down

Figure 17: Flowchart for Dave's and Johnny's machine

The focus was now different from before. They were predominantly concerned about how their car would meet the external criteria of including three separate machines. Johnny, who had spent a good deal of time visiting with other groups knew quite a lot about what sorts of things other student were doing to address this issue. He suggested mounting a ramp on their car and having a golf ball roll off the ramp when the car bumped into a barrier. This idea led them to address the question of where the golf ball should end up. Dave was unhappy about abandoning their original quest but the crunch of the looming time constraint was compelling. He suggested the inclusion of an "Atwood's machine" pulley system. The car would deposit a golf ball into a cup (one end of the Atwood's machine) positioned at the top edge of a table and cause a 50 gram mass to be lifted upwards as the cup was lowered to the floor. I seized upon the idea and said that I thought it could be built with some wooden doweling I had in the classroom. Five minutes later they were building and cooperating again as if they had never been untracked.

This change represented a major shift in the boys' orientation to the problem. Dave and Johnny had envisioned a self-contained machine in which all the linkages were internal. The range of influence could be maximized (as the car moved some distance away from a starting point). Now their machine had evolved into a Rube Goldberg style machine in which different parts were essentially pasted together - i.e. - the golf ball and ramp were stuck on top of the car, the "Atwood's machine" was stuck to the edge of the table and the linkage between them had to be monitored and manipulated in order for it to work correctly. The machine could no longer be picked up and held as a whole unit and it was no longer free to move in the same sense as the original car was free to move. In a sense the boys had, at the last moment, abandoned their own internal criteria for success and adopted the more public external criteria which Ms. B. had assigned. After the project had concluded, both boys, especially Dave, were still unhappy about how they had lost track of the idea that had seemed so promising. During my interview with them Dave and Johnny seemed dejected and they both slumped in their seats as I asked them questions. **What happens to a person's understanding of a process for engaging the world when the shape of the problem changes so dramatically that one can no longer see any connection to the shape which was originally considered meaningful?**

In the presentation of their machine to the rest of the class Johnny and Dave did not describe any of the actions and inventions they had brought forth through the previous week. Their presentation focused on three aspects: (a) the three simple machines they had included; (b) how it worked; and (c) how energy was involved in their machine. Figure 18 presents their written analysis.



Analysis

The task that our machine performed was to power a car with batteries and a motor and bumt into a curb(wood). A golf ball would then run down an inclined plane which was on the front of the car. The golf ball would roll across the peice of wood and fall into a cup which was tied to a pulley. When the ball landed in the cup it would go down the pulley and send a 50g weight upwards.

All the specifications to our last idea were met. The car must go 40cm and must have stoped in a in a way that the golf ball which was on an inclined plane attached to the front of the car rolled down it. It must have travelled in a forward motion and landed in a cup attached to the pulley. These specifications were all met. The originol idea didn't meet all of it's specifications though. It was supposed to pull a heavy weight a long distance but the car was unable to do that becouse the car didnt go fast enough and didn't have enough power

Figure 18: Johnny's and Dave's written analysis

Johnny's and Dave's analysis gives only cursory mention to the difficulties they encountered during the week of building. The sense of having lost something they considered to be important is not mentioned. Perhaps this is not the kind of portrayal that students will spontaneously include in a written report. My sense of the strong emotional connection they had for their early success emerged out of my interactions with them during the building and testing process.

Table 3 presents Johnny and Dave's responses to the reflections worksheet.

Table 3

Johnny's and Dave's responses to the reflections worksheet

We liked the fact that our simple machine actually worked. We also like that our machine isn't too simple and we like the design. We found that putting the motor and batteries together turned out to be pretty easy. The difficulties were getting the car to be stable and able to hold weight while actually moving. We found out that we can use motors and we know how to use them very well now. We thought that the motor and the type of batteries that we used were going to make the car travel at a medium speed while carrying a load. But what we found out was the car still moved very slow and at times didn't move at all.

We were very limited in time. While we were working on our project we came up with many ideas. When our first idea didn't work we decided to use some of the those ideas. But they didn't work either. When our last lunch hour came we used it and got to work right away and ended up finishing.

We did not accomplish as much as we set out to do. [If we were to do this project again] we would probably start off by using one of our other ideas and work further into it. We would change the design of the model and try making the motor more powerful and the batteries more powerful. We would try planning it more differently and give ourselves more time to plan out our idea so we could be assured a positive project.

Dave and Johnny (me) worked very co-operatively. We tried to split the work in half and did a good job of it. Dave did most of the work on the project while Johnny (me) did most of the writing.

The issue of "working" or "it works" is important. What happens to a person's conception and understanding of their way of working and building understanding when their primary concern is whether or not their "machine" works? Dave and Johnny accomplished many significant things in their original building engagements. For instance, they considered themselves to have learned significant things about using motors and batteries to put something in motion and they had constructed a series of ingenious and complicated gear systems. However, it seems that their successes were enveloped by a perceived shroud of failure, and failure or the actions leading to failure were not considered by them to be worthy of presentation or discussion. This issue will be addressed in more depth in another section.

A possible range of decisions might involve trying to fix the source of the difficulty, revising the design, or reconceptualizing the problem. In focusing on speed the boys seem to have lost track of trying to think about simple machines in their car. Perhaps part of the motivation for this came from a sense of competition from the boys next to them who were building the rocket car. Another part of the motivation perhaps came from the freedom of exploring the thing which was most important to them, namely building a device which would go fast and far.

Dave and Johnny experimented and played with the LEGO because it was an affordance which provided the most obvious and immediate possibilities for action. It does not appear that Dave and Johnny attempted to locate the source of the difficulty which was impeding their progress. Rather the boys began to try to incorporate more complexity in the design of the car chassis and gearing system. As the gearing became more complex the boys became more frustrated with the fact that their car would not go, In each case the boys would start up their car and watch the wheels move freely as they held the car in the air. but when they placed the car on the floor the extra load on the car was always too much for the hobby motor and the car would not move.

The "shape of the problem" at any point is a snapshot of the dynamic processes of coemergence of the actual and possible. Various contexts of interpretation can be applied to the next phase of the boys engagement with their task. As frustration level grew and bickering developed the possibility of relinquishing participation in the project was a choice of Johnny. In effect, he seemed to avoid his own workspace and spent much of his time visiting other students' workspaces.

Dave and Johnny engaged in the process of building a car in different ways. Each day they set up their work station at a common place in the classroom. Dave always seemed to be positioned to that he was closest to the pieces as they lay spread out on the table. Johnny was nearby but he seemed to defer to Dave when it came to handling and using the pieces. For instance, Dave seemed to control the most important pieces such as the wheels and the gears. Dave appeared to do most of the assembling while Johnny mostly observed and made comments and suggestions. Dave seemed to prefer to stay close to the LEGO pieces throughout any classroom period while Johnny often traveled about visiting other work areas in the classroom. Whenever there was something to be acquired such as battery or motor or piece of wood it seemed as if Johnny would volunteer to make the trip to a resource station to acquire these items. Often he would return from such a trip, deposit the item that he acquired, and then return to visit another table where something had caught his eye. Neither Dave or Johnny seemed unhappy with this arrangement. It seemed as if an arrangement was in place, Dave would do the construction work and Johnny would do the written work.

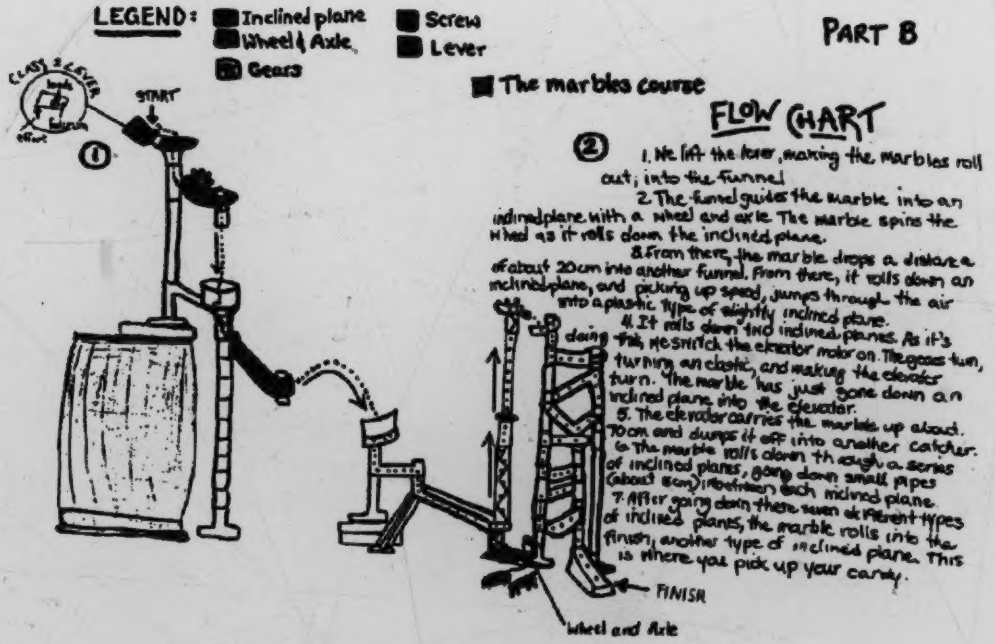
What happens when a person cannot find a way to engage which works for them? To what degree is it important to already have a world in order to begin shaping it or developing a way of engaging it? What happens when a person tries to steer a trajectory of action-thought toward a specific goal without understanding the plastic nature of the experience of laying down a path in walking (i.e. aiming too far into the future)?

This point was illustrated in the building experiences of two girls, Leena and Samantha, who I spent much time trying to help. These girls were trying to build a machine that moved a kettle (they called it a tea pot) from one place on the surface of an imaginary stovetop (i.e. an upside-down box) to another place on the imaginary stovetop. This was the general description of their idea which remained essentially unchanged throughout the project. Leena and Samantha had trouble finding a way to build specific design ideas in order to begin to make their general description emerge. As it turned out one of the girls, Leena, was absent for several classes in the middle of the project. The remaining girl, Samantha, was left to work alone and approached me for help. Her workspace was on the floor at one side of the classroom and we sat down there. As Samantha tried to explain what she wanted to do, she would repeatedly pick things up and move them about, acting out the movements she wanted to make happen. However, she seemed to be unable to begin connecting her ideas together into a larger framework. It seemed easy for Samantha to explain what she wanted to do by moving pieces to want to put the whole thing in motion without putting any pieces in motion. She seemed to accomplish this by inserting herself into the process she was trying to create. However, she was not able to find a way to remove herself from the process and recreate the movements she had enacted with a physical device (i.e. a string and weight sliding on a ramp or falling from a pulley system). On several occasions I got down on the floor with Samantha and helped her build a component after she explained and demonstrated a kind of movement she wanted to make happen (e.g. a pulley mounted on a metal retort stand with a falling weight). Often she would seem to be building successfully and I would leave to help other students who had requested help. However, it seemed that Samantha would inevitably lose track of how a specific component she was building could fit into the larger whole of her design. In fact, it is not clear to me that Samantha was ever able to visualize the collection of individual parts with which she surrounded herself as a larger whole that could potentially be connected to her general understanding of the problem. She seemed intent on making the entire idea work in one "fell swoop". The strategy of breaking the problem into constituent parts and focusing on each of them in a systematic way seemed to be an approach that had little meaning for Samantha. Although Samantha and Leena did not accomplish the goal they had originally set for themselves, they never gave up trying and by the end of the project they had assembled a partially working machine which required some intervention by Samantha to operate.

It seems that Samantha and Leena's relative inexperience (as compared to most of the other students) in physical building and their apparent focus on bringing about one single outcome made it more difficult for them to see significance in the construction process in which they were engaged. Perhaps a reformulated problem context (e.g. acquiring parts for her own machine by de-constructing an existing machine invention) would have helped Samantha visualize and enact possibilities that she was unable to bring forth in the Invent a Machine project. Entering into a process of building by un-building (i.e. deconstructing an existing building design) may be a viable way for some students (i.e. Samantha) to begin inventing their own new ideas.

What can a process of repeated building and un-building allow for students who incorporate this approach into their action-thought? My experience with two girls from the Invent a Machine project allows me to add some insight into how this question might be answered. Linday and Sasha built a device that they referred to as the "Gum Delivery" and/or the "Candy Dispensing" Machine. It appears that they had a good sense of the trajectory of action-thought that they enacted in developing their invention. They seemed to begin the building process without a specific destination in mind. Perhaps they simply wanted to explore and enjoy the organization and movement of the equipment Linday had brought from home. This equipment consisted of a large (1 m tall) motorized vertical screw and a set of plastic tubular pieces. It made for an impressive display in their workspace in the classroom and most students visited their table to see the motorized screw transport a marble above the surface of the table.

Linday and Sasha explored several combinations of the pieces in constructing an assortment of pathways for a marble to move through. Their project seemed to be in a constant state of flux as they engaged in a repeated process of building up and tearing down. As their project developed a purpose seemed to emerge for their machine and by the end of the project they were referring to their construction as the "candy dispenser" (see Figure 19).



FLOW CHART

1. We lift the lever, making the marbles roll out; into the funnel
2. The funnel guides the marble into an inclined plane with a wheel and axle The marble spins the wheel as it rolls down the inclined plane.
3. From there, the marble drops a distance of about 20cm into another funnel. From there, it rolls down an inclined plane, and picking up speed, jumps through the air into a plastic type of slightly inclined plane.
4. It rolls down two inclined planes. As it's doing this, we switch the elevator motor on. The gears turn, turning an elastic, and making the elevator turn. The marble has just gone down an inclined plane into the elevator.
5. The elevator carries the marble up about 70cm and dumps it off into another catcher.
6. The marble rolls down through a series of inclined planes, going down small pipes (about 8cm) in between each inclined plane.
7. After going down these seven different types of inclined planes, the marble rolls into the finish, another type of inclined plane. This is where you pick up your candy.

Figure 19: Linday's and Sasha's Candy Dispensing machine

In the interview, Linday and Sasha spoke of the emergence of an holistic awareness of the shape of the process they had just enacted. They also commented that they felt this new understanding would help them visualize ways of participating in the upcoming science fair. Later, I met Linday at the Edmonton city wide science fair where she was presenting an investigative project she had done with Amy involving the design, building and testing of model airplanes. It seems that there is a circular feedback relationship between the shape of the problem and viable action-thought. Understanding of the overall shape of the problem contributes to the emergence of viable action thought and vice versa.

The Mousetrap Powered Car Project

Classroom or school settings are usually the broadest contexts into which a researcher can extend his/her engagements with students. It is rarely possible for a science education researcher to directly explore the shape of action-thought outside the science classroom in terms of its shape inside the classroom. What qualities does the shape of a classroom problem develop when an out of school component to action-thought is incorporated into its portrayal? A combination of fortuitous circumstances allowed me to explore the interplay of in school and out of school patterns of engagement for a tenth grade academically oriented science student working on the **Mousetrap Powered Car** project.

The Mousetrap Powered Car project was a culmination of a physics unit on motion and energy from the science curriculum. This project is similar to a popular science olympics event in which students design, build, and test a device which accomplishes a specific goal. In this project students had four weeks to design, build, and test a car powered by a mousetrap provided by the teacher. This time period included a two week Christmas break.

The assignment was graded according to two criteria. First, each car was required to launch with a switch and had to transport a raw egg four meters in the shortest possible time. Second, each car was assessed by a panel of external judges for its aesthetic qualities. Mr. G. told his students that they could receive bonus marks for their work on the project if they kept a detailed record of how they worked during the project. Since most of the work would be done out of school, students could choose their own method (i.e. written, audio, video) to make such a record. Ian's group chose to make a video-record of their work. The instruction sheet given to students is presented in Appendix B.

I chose this classroom as a research setting for two reasons. First, the classroom teacher, Mr. G., was well known to my supervisor and was highly regarded as a teacher who engaged students in self-directed, open-ended activities. Second, Dan and Tristen were members of Mr. G.'s grade ten science class, providing me with a potential opportunity to extend my research relationship with them for a third consecutive year. When Mr. G. learned of our research interests he invited me to become involved in the Mousetrap Powered Car project.

I joined the classroom on a continuous basis about ten days before the project began in order to get to know students and develop a sense of the dynamics of their learning environment, especially when they were working in "hands-on" laboratory sessions. During this period of time one of the students, Ian, identified himself as the son of one of my supervisor's colleagues.

I initially became interested in Ian's engagements in this project because the members of his group agreed to provide a video documentary of their project. After Mr. G. announced the details of the project , students immediately formed their groups to discuss the design of their car. As I talked with Ian and the other members of his group I noticed that they did not seem to be as focused as some of the other groups in making plans for their car. They seemed preoccupied with the idea that they were going to transport a raw egg and joked about building a "seatbelt to insure the safety of the egg". When I said that I thought a seatbelt was a good idea one of them replied "well we really need the marks" and the others nodded in agreement. As I was about to leave Ian offered that he already had a car at home. "It was built for distance, not for speed, but we're going to modify it for this project" he explained. I thought Ian must have been working at home in anticipation of the project (Mr. G.'s Mousetrap Powered Car project was well known in the school) and asked him to tell me more about his car. I also said that I would like to see his car if he could bring it to school. He said that he might be able to bring the car to school but he seemed reluctant to describe the car in more detail. I attributed Ian's response to shyness and left it at that.

What can be said about the case that I have outlined so far? From a theoretical perspective I consider "shape" to have a tripartite metaphorical quality. First, the nature of a person's engagements with the phenomena emerging from a problem has a distinctive rhythm or shape. Second, there is a shape to the structural coupling between a person and a problem. As the shape of the problem evolves, so does the structure of a person's embodied engagements with the problem and the setting. Third, the setting itself and the constructions which emerge have a distinctive and dynamical shape.

As teachers or researchers in science education we generally assume that the problem which is assigned is the same as the problem which is enacted by students. In many cases this is a reasonable assumption. We generally overlook the circumstances that compel students to transform teacher assigned problems into new problems as they construct and enter into a context of action-thought. Any context of action-thought incorporates assumptions. In this instance, Mr. G. assumed that the students already had enough experience to design and build a simple device because he gave no instructions or handouts to the class about possible designs of basic model cars. Perhaps this would seem to be a reasonable assumption, given that these were academic grade ten students. However, I noticed that most groups of students had at least one person who was designated as the builder. In most cases this occurred because the person had the most building experience and in other cases it was because the person knew someone else with building expertise. Students also formed groups which included at least one person who was considered to be the "smart one" in science. Most students seemed to have little or no experience in building things from scratch. In Ian's case, he was designated as the "primary builder" for his group.

I became aware of some interesting out of school contextual factors from comments made by Ian's Father, who was aware that I was involved in a research project in his son's science class. I discovered that Ian's younger brother Graeme had become involved in the project. When I learned that Ian and Graeme were interested in talking to us, my supervisor and I made arrangements with their parents to interview the boys at their home. The purpose of this interview was to explore the influence of out of school contexts on how the meaning of a problem takes shape for its various participants. We interviewed Graeme and Ian at their home one afternoon. As an aside, this group project turned out to be very successful within the context of the science classroom. However, this was not a consideration in my desire to interview Ian and his brother at their home.

Ian and Graeme were prepared for the interview. We were seated at the kitchen table where two cars were on display. I recognized one car as the one Ian and his group had used in class. The other one I had never seen before. Graeme, who was in grade eight, described it as their "practice car". Ian seemed eager to explain that Graeme had played a significant role in the design and building of the car.

> **Leo:** Oh yes, Ian, I remember you telling me on the first day that you already had a car.
>
> **Ian:** Graeme had already found out how to make the design of the mousetrap. So when I came home and told him I had to make a mousetrap car he knew exactly how I should put it [together] and he did a lot of it.

As our conversation developed it became clear that the evolution of the project for Ian and the other members of his group was more convoluted than I had expected. A complex social dynamic played a crucial role in determining how the various members of the project participated in its evolution. It seems that everyone wanted to contribute to the design and construction of the car at the beginning of the project. However, it quickly became apparent to the boys that they were not going to be able to work together outside of school on the project. Three of the boys, Ben, Sandy, and Trent were able to work together outside of school but Ian was not able to meet the other group members except at school. When Ian told the others about his brother's already working model everyone agreed that he should begin the construction of the car. When Ben announced that they could use his parents' video camera at his home, it was agreed that he, Sandy and Trent would assume responsibility for making the video documentary. It seems that the boys did not understand the consequences that this division of labor would have on the shape of their involvement in the project until well into the project. In the comment which follows, Ian contrasts his own and Graeme's contributions toward the successful completion of the project with those of the other members of his group. Ian recognizes the significance of the shape of his involvement in building the car with Graeme:

> **Ian:** Those guys were going to do the documentary because it's sort of an independent project. I mean unless one of those guys was over at my house all the time we couldn't really work on it together because it's just that you can't really work it that way. So Graeme had some time and he helped me build it. Really, he should have been my partner.

It is interesting that a grade 8 student should play such a crucial role in a grade 10 project. Perhaps students from a wide age range can successfully participate together in projects which require design and building. However, they must be able to work together (side by side) in order to be successful. The fact that this was not possible for the other members of Ian's group had a profound impact on the shape of Ben, Sandy, and Trent's involvement in the project. For them, the shape of the problem changed from engaging questions surrounding the nature of the design and construction of the car to thinking about making a movie about the car. For Ian, the shape of the problem became even more complex. He had to understand the design and building process well enough to explain the car to the other members of his group in a way that convinced them to "go with it".

Students naturally create and use **affordances of action** in order to shape their problem-environment and the way they engage the problem-environment. Affordances of action may simply be thought of as possibilities for action or degrees of freedom which are brought forth into significance by the persons acting in the problem-environment. These affordances may emerge from the setting, from the persons themselves or from the way that the persons engage the setting. Because each of the three are dynamically changing we can say that affordances of action co-emerge with the persons, their setting, and the persons' way of engaging the setting. In other words, the three elements interact in such a way as to define each other.

A problem may be thought of as existing in a space or environment consisting of three essential elements: persons, their actions, and setting. The complex interdependence of these three elements tends to have a dispersive effect on the shape of the problem. In other words, the shape of the problem has a natural tendency to change as a consequence of its interaction with its environment.

For Ian, Graeme's prior experience in designing and building a mousetrap powered car became an affordance which he brought forth to significance because of the nature of the school problem-context, the nature of the way he and the others could engage the school problem context, and the nature of Ian's own personality. The school problem-context required design and building. These were things that Ian knew he could do effectively with his brother. When Ian's group discovered that he could work together with them, the affordance of Graeme's experience became even more significant to Ian and to the others. If Ian had been able to work together with the other members outside of school would Graeme's role have been the same? I think probably not. For Ben and the others, Mr. G.'s inclusion of an optional component in the problem and the availability of a video camera became affordances which were brought to significance by the way that the boys were able to work together.

For Ian's group, the possibilities for action co-emerged with the evolving context for action. The boys re-shaped their problem-context so that it "fit" with the possibilities for action available in the problem-context. As a consequence of this re-shaping the possibilities for subsequent action-thought in the problem-context were changed. Ian engaged with his brother in actions focused mostly around learning how to design, build, and test the car. In his dealings with Ben, Sandy, and Trent, Ian engaged in actions focused mostly around teaching them how the car worked and how to make it perform successfully in the final performance tests. Ben, Sandy, and Trent engaged in actions focused mostly around constructing the video documentary.

The shape of Ian's engagements with Graeme form a central part of the shape of the problem for him. Some of the complexity of that shape are illustrated by the following sequence from the interview:

> **Leo:** I want to talk about the way the two of you work together. Maybe you could compare the way the two of you work together to the way you work with anyone else? Is there a difference?

> **Ian:** Yeah. We tend to talk a lot more about social things with friends at school and less work gets done than when you're with your brother at home. I did a lot of painting on it though and I asked him for a structure because I wasn't sure about a design in making a mousetrap work and making the back wheels spin but Graeme knew what it would be.
>
> **Leo:** So you were looking from Graeme for a concept of what might be workable?
>
> **Ian:** Yeah, because he's pretty mechanical at these things.
>
> **Heidi:** Have you built other things together?
>
> **Ian:** Not really but I think that when he already had a structure done so when I told him that I needed to build a mousetrap car he took it apart and he sort of made the very same kind of structure with the mousetrap and the extension but **I sort of followed how it was being built the whole time.** I think that if you followed the mousetrap car being built you don't have to ask as many questions before the race and questions take away from building time and so that's why I think I understood how it's supposed to go and all we had to do was paint it and make a few test runs.

Ian's introduction of the notion of "following" is interesting. Normally, this kind of engagement would not be considered by a teacher/researcher to be viable. However, it seems that Ian considered a process of "following" Graeme's actions be a viable part of his process of understanding. This notion adds complexity to the idea of being in contact with a device during a building activity. It seems that even though Ian relinquished the role of "lead designer" to Graeme he still maintained a physical contact with the processes of designing, building, and testing because both he and Graeme considered himself to be fully implicated in a process of bringing forth significance.

Shape of Structural Coupling

How does a student's structural coupling with a science problem contribute to the development of his/her understanding? One way to address this question is to consider the extent or degree to which a person is structurally coupled to their environment.

The degree of Ian and Graeme's **structural coupling** with school science seems to be somewhat different. For instance, Graeme considers himself to be "good" at science while Ian does not. "Science is most often my favorite subject" explained Graeme while Ian describes his experiences with school science as follows:

> **Ian:** High school science really intimidated me. It still does. I think that anything with a lot of math in it and anything that is semestered is sort of hard, for me at least. But I enjoy it with Mr. G., I think he is a good teacher and he knows a lot about science.

Ian recognizes that his structural coupling to school science is different than Graeme's. He seems to feel that success in school science is more difficult for him to achieve than it is for Graeme. However, it seems that for Ian it was not the intensity of his structural coupling to science that was so important for him (he indicated that he did not intend to study science after high school); rather it was the shape of his structural coupling to the Mousetrap Car project that was most important to him. For instance, his decision to include Graeme in the project seems to indicate that Ian felt there was a way for a "viable trajectory of understanding" to emerge for him as he worked alongside Graeme even though he considered Graeme to be "better at science" than himself. Perhaps the most significant aspect that the Invent a Machine project provided Ian was that it allowed him to interact with the action-thought trajectory that Graeme brought forth and co-experience with Graeme the process of shaping the Mousetrap Car problem.

It is often the case in school science projects that students of different interests and abilities work together. As teachers, we often attempt to form mixed ability cooperative groups where separate groups are equitable in terms of the collective sum of the abilities or interests of individual group members. In terms of structural coupling we could say that we are attempting to maximize the degree of structural coupling within each group while minimizing the differences across groups. This would seem to be a reasonable pedagogic decision because it attempts to give everyone an equal opportunity for success in projects where they are asked to collaborate with others. However, is the degree of structural coupling between a collaborative group and a problem really what is most important? It may be the **shape of the structural coupling** between persons and problem, rather than the strength or degree of the coupling, which is most important in allowing the members of a collaborative group to engage in viable action-thought.

I believe that a consideration of the shape of structural coupling allows a more explicit and appropriate connection to be made to the social complexities introduced by the collective nature of group thinking. Maturana and Varela (1987) treat structural coupling as a phenomenon of degree which occurs between a person and her/his environment. As such they provide no explicit way for a collective person-person component to be included in action-thought. In order to extend Maturana and Varela's (1987) structural coupling into a group setting one is forced to assume that the degree of structural coupling of the group to a problem-environment can be described by a linear sum of each group member's individual coupling to a problem-environment. This is not satisfactory because it assumes that group thinking does not have non-linear characteristics and that all members of a group structurally couple with the same problem-environment. As I have already suggested, both of these assumptions are problematic. Therefore I propose that a more appropriate way to include the collective nature of group thinking into a discussion of structural coupling in social group work is to consider a new component of structural coupling which I call the shape of the structural coupling.

A difference in the shape of Ian and Graeme's structural coupling with the problem is illustrated by the ways they each of them interpreted and described the purposes of their involvement in the project.

> **Leo:** Why do you think your teachers get you to do a project like this?
>
> **Ian:** For me or Graeme? (turns to Graeme) Why, Graeme? For you.
>
> **Graeme:** Well I think it's to make us not always do straightforward ones wherever you watch something. **The best way to learn something is to actually do it yourself, not by watching someone else do it all the time.** I know that's the easiest way that I can learn something. I know for our science midterm ... there were lots of questions ... and all I had to do was think back to the car and I right away got the answers because I was just thinking of the way that it was built.
>
> **Ian:** For me, I don't think it was that, but I think it is taking initiative yourself into making something. **Not just learning something from your teacher teaching it to you but learning something from teaching it to yourself, and teaching it to your partners that you're working with** ... Graeme would have made the structure and he explained to me why something would work and I would explain it to the rest of my group why it would work. I think that's how you learn to understand it.

Graeme has clearly integrated action-thought into his understanding process. He re-enacts personal action-thought experiences in order to convey his understanding. Ian, on the other hand, seems to consider his role as a teacher among the members of his group as contributing significantly to his own understanding. Both boys consider action-thought to have contributed to their understanding. Each one talks about understanding, but in somewhat different ways. Perhaps this is a consequence of the differences in the shapes of their structural coupling to the problem.

A third illustration of how the shape of Graeme and Ian's structural coupling to the problem was different is illustrated by how each of them viewed the project in the context of the curriculum they were studying. Mr. G.'s intentions were that Ian and the other grade 10 students would make connections between the physics concepts they were learning (force, energy, and motion) and the practical problems they encountered and solved in building the mousetrap powered car. Graeme's teacher, on the other hand, engaged students in an almost identical project in order to learn about simple machines, which is a topic in the grade 8 science curriculum.

> **Leo:** How would you compare this kind of a project with the other kinds of activities you do in science?
>
> **Ian:** This [project] is different than every other one that we did I think. It was supposed to be a fun project I think, more than a class project, because it's not part of the curriculum. So we've never done something like this before. I think every year since junior high I've always done something fun or the teachers try to make you do one fun project for the whole year . Like we built a bridge in grade seven, I forget ... oh yeah, we made dioramas in grade nine, like we made solar houses. But this [project] didn't take any written work. You didn't have to give them a written copy of your ideas or anything whereas in grade nine we had to give them a big written report to hand in.
>
> **Graeme:** We have a lot of assignments similar to this one with our teacher. Before this we had to take apart an appliance and do a big blueprint of it to scale. Later on in the year we're going to have to make a machine to perform a task. It's kind of a fun thing.

Ian and Graeme both had experience in action-thought building projects. However, Ian does not seems to consider this kind of project to be a part of the curriculum whereas Graeme does. Perhaps this is a reflection of their teacher's views. This may also be a consequence of the fact that Ian engaged in these kinds of thinking on a rather sporadic basis whereas Graeme seems to have been more regularly involved in action-thought as part of his science learning experience. It seems that Ian did not clearly understand how the mousetrap powered car could be connected to the curriculum he was studying. For instance, when I asked him if he would change anything about the way the cars were evaluated he replied:

> **Ian**: I would. I think I'd have the kids have to explain exactly how they built the car in front of the class before they raced it and why they did the things that they've done. Then you could probably show that you've participated in it, that you understand and maybe take it apart and put it together for the teacher. But for grade ten I don't think we need to know about simple machines so this was just ... I'm not sure why we did this. I think it was part of the academic challenge part of the course because it was Science 10 AC. I don't think Science 10's did it.

Ian seems to have interpreted this project more as a challenge peculiar to the academic status of his grade 10 class rather than as an activity with a specific curricular focus. It seems that Ian learned a lot about making the car work by interacting with his brother at home and his group partners at school but it is not clear that he thinks this has contributed to his understanding of the physics concepts. The shape of the problem, as it was described by Mr. G. at the beginning of the project, had taken on a new shape for Ian as he, Graeme and his school partners worked on the problem.

> **Heidi:** Is there anything that you would like to tell us that Leo hasn't touched on? Something that you think was important in this project.
>
> **Ian:** Not really, except I think part of the motivation to making a really good car was the other groups always telling you "Well we're going to beat you because our car is a lot better than yours." or "Our car can go this fast, how fast can yours go?" ... Besides, the marks ... Mr. G. had said that you get a hundred percent if you're the first car, to win. That's also a major motivation. But both of those make you really try your best on a car. That's what I felt. I want it to be the fastest car still, but everybody wanted that though.

The shape of Ian's structural coupling to the problem changed during the mousetrap powered car project. At the beginning of the project, Ian appeared to be one of the least assertive members of his group but by the end he had became the group leader. For instance, Ian insisted on preparing the car for its final evaluation during the classroom tests after Ben failed to operate it properly in the first trial.

> **Leo:** You were responsible, Ian, for the "runoff" in Mr. G.'s class, I noticed.
>
> **Ian:** Yeah, well I didn't want anyone to do something wrong because I remember that Ben had not wound it up properly. He had wound it up over a part of the axle so when we started it the thread wound around the straw and made the whole car not work.

Clearly Ian had taken ownership of the car and the project and considered himself the best equipped to ensure its success. In fact Ian's way of being in his grade 10 science classroom had changed. I had observed Ian act together with his classmates, in classroom and laboratory settings, before the project began. Ian's way of being during that period can best be described as reserved. He rarely inserted himself into classroom discussions and seemed content to remain on the "outer perimeter" during group engagements in laboratory activities. What factors contributed to the transition to a more assertive role for Ian in the mousetrap powered car project? Perhaps it was a consequence of a new-found confidence acquired in working together with his brother. Perhaps it was a result of the significance of his new role in explaining the car to partners whom he did not know very well (Most students knew at least one other student in the class from Junior High School - Ian was one of the few who did not know anyone in the class). In any event, Ian had changed his way of acting in his classroom science, at least during the time that he was engaged in the project.

Shape of Ian's structural coupling to social dimensions of the problem

I think that Ian found himself in the position of being the person from his grade ten group who was most responsible for the performance of the car. The shape of the social-cognitive dimension of Ian's structural coupling to the Mousetrap Car problem was unique in that he had to manage his understanding of the problem in several social contexts i.e. with his brother, with the other members of his group, and with his Father. Each of the three social-cognitive contexts contributed to the development of Ian's understanding.

> **Heidi:** How about the other members of your group? I mean there were three other people in the group. Will you tell us about some of the ways you were working with those guys?
>
> **Graeme:** They really wanted to get the three-wheeler so they really messed around with the front part of the car. After it came back, it was broken.
>
> **Heidi:** So what happened was that you had the prototype and then Ben and Dan came and ... ?
>
> **Ian:** Graeme and I told them don't take it apart because it's in good shape and it will go fast now, but somehow Ben just messed it up.
>
> **Heidi:** Did you worry about it when it was at Ben's house?
>
> **Ian:** Yeah.
>
> **Graeme:** And at that time it wasn't so stable and when it came back that's when we decided to do this (points to "new-parts" car) because that car (points to "Ian-Graeme" car) wasn't working anymore.
>
> **Leo:** Because of the front wheels?
>
> **Graeme:** Yeah and the back sprocket wasn't working.
>
> **Ian:** They messed up the string.
>
> **Graeme:** And the back sprocket in back here. Everything here is now strengthened. We wanted to reduce any more accidents happening so under here is more dowel attached.
>
> **Leo:** Oh yeah, I see, a cross bracing.

Graeme: Yeah, a cross bracing. We didn't use a triangle support. I know that would have been stronger but we just decided to use a square and like it's really hard to break now if you stepped on it.

Science classrooms are complex social-cognitive environments. Some aspects will be discussed in Chapter 8.

On working together with his Father on the problem

I am not sure how Ian's Father became involved in the mousetrap powered car project. It seems likely that he must have noticed Ian and Graeme working together at home after school on Ian's science project. He probably considered this to be somewhat unusual because the boys said in the interview that they had never worked together before to build something for a school science project. It is also possible that Ian's Father noticed that Ian was under a lot of pressure to produce a car that would satisfy many other people, especially after the original car was returned broken from Ben's house. It is not unusual for a parent to be concerned when their son or daughter's performance depends on the performance of other students. In any event, Ian's Father chose to enter the project by purchasing a selection of prefabricated wooden materials.

Heidi: (points to "New-parts" car) Did I hear you say you built that car first?

Graeme: No. Actually, originally we built this one (points to "Ian-Graeme" car) and it was the original model and ...

Ian: (points to "Ian-Graeme" car) It wasn't working.

Graeme: Well **it was working,** but it wasn't working totally and ...

Ian: We got frustrated with it and my Dad went out and bought parts for this one (points to "New-parts" car).

Leo: (picks up "New-parts" car) This car was developed after that car?

Graeme: Yeah.

Leo: Really? Even after the project was done?

Ian: When we raced on a Friday, this one (points to "New-parts" car) was done the weekend before the Friday.

Graeme: Originally my brother and I had been developing this one (points to "Ian-Graeme" car) and then we were getting pretty fed up with it and my brother wanted to get a really good science mark so he wanted to get a really good car and so my dad decided to go out and buy these parts and then we could get a really good science mark.

> **Ian:** But the parts bought didn't work nearly as well.
>
> **Graeme:** I wasn't really in favor of it because I was really into this car (points to "Ian-Graeme" car) so I kept it in my room and I did modifications by myself on it and then on Thursday night before we raced we just brought them downstairs and then this one (points to "Ian-Graeme" car) ended up going faster because of the modifications.
>
> **Ian:** (points to "New-parts car) This one went but it kept on going sideways.
>
> **Graeme:** It was probably because the wheels were not on totally straight.

The social dynamic of the project became complicated for Ian and Graeme when their Father decided to enter the project. It appears that Ian and Graeme's structural coupling to the problem changed in the last few days before the project's final evaluation took place. Graeme somewhat withdrew from the process as he worked alone in his bedroom to improve the original "Ian-Graeme" car. Ian, on the other hand, worked with his Father and the new materials to build the "New-parts" car. Perhaps Ian's Father was concerned that Ian was too willing to defer to Graeme's expertise in making decisions about the design and construction of the original car. Perhaps he didn't think it was appropriate for Ian to be using essentially the same car that Graeme had used in his grade 8 science project. Or perhaps he was simply concerned that the two boys were devoting too much time to one science project (each boy was an accomplished musician and devoted a significant portion of time each day to music). In any event, his Father's decision to enter the project seems to have played a significant role in the development of Ian and Graeme's understanding of the project. However, in retrospect, Ian and Graeme consider their own collaboration to have been the most significant to the successful development of the project. The importance they give to working independently is illustrated by Graeme's comment:

> **Graeme:** Originally I wanted to make my car out of balsa wood but my dad thought it was too expensive for a science project and so none of this equipment we bought for this car, it was just stuff lying around the house. I know at my school for the race all the parents got involved **but in this car** (points to "Ian-Graeme" car) **it was really just Ian and I.**

Perhaps this illustrates one of the most important components of the shape of problems which allow students to bring forth significance and to develop understanding. Independent action-thought allows viable action-thought to be shaped and re-shaped.

In this chapter I have provided four relatively detailed analyses of the dynamics of the shape of the problem ranging from a clinical study in non-curricular environment to a complex shape with a strong social dimension in addition to the challenges of working effectively in a competitive classroom environment. Clearly, actualizing the possible is a complex activity. I now turn my attention to the nature of making things in Chapter 7.

Chapter 7: Building Things

Building things physically is part of the process and building things mentally is the process. (Dan, 1996)

The reader will have noticed that all but one of the episodes that I have described or reconstructed involve students engaged in some type of building activity - an activity in which the students are called upon to bring forth a design and transform it into a material object or device. To this point I have interpreted these activities within an enactivist framework which includes Varela, Thompson and Rosch's (1991) concepts of structural coupling, embodiment, adequate conduct, coemergence, and recursive action. I will now turn my analysis toward a closer look of aspects of the building engagement itself.

Building things is a particular kind of enactment in that the stages in its genesis and development are visible to others. Building things also encompasses a kind of personal embodiment which I will attempt to describe. The reader will have noticed that in each of the instances that I have described the structure that was built has been present. The students in the machine building project held and demonstrated their creations as they talked to me about how their thinking developed. The home interview with Ian and Graeme was structured by them so that the cars were the focus of the initial part of our conversation when we sat down to talk. In numerous conversations with students it seems as if the structure is viewed by its creators as an extension or embodiment of themselves. Indeed, when I asked students about what they had learned in such an engagement they often responded in terms of discoveries of their own capabilities to be able to do new things.

What is special about the physical engagement of building as a learning experience? In this chapter I will explore this question from a number of perspectives. How is building experienced by the students within the context of their school assignments? Can these accounts be analyzed in a phenomenographic way to reveal a number of qualitatively different approaches to action-thought? How is the building engagement experienced by me when I am acting together with students? In what sense is the physical engagement of action-thought a kind of enaction as suggested by Varela, Thompson and Rosch (1991).

Ms. B.'s grade eight classroom with the **Invent a Machine** project and grade nine classroom with the **Solar House** and related projects are already known to the reader through my presentations in earlier chapters. Wide latitude was given to the students in these projects as to with whom they would work, where they would locate their building site, and what criteria would be relevant for the assessment.

During the Invent a Machine project, I was engaged with the students in a way that involved me as a participant in their action-settings, not simply as an observer. What particular insights did this allow me to generate? In addition to focusing on specific students I will "travel the classroom" in describing the progressions in action-thought as they unfolded. Also integrated into this account are descriptions of how the students were thinking. Such descriptions are based both on what the students said and what we enacted together as the project evolved.

"Making things" matters: A perspective on engaging in an action environment

The reader has met several individuals or groups from the Invent a Machine project. I will now present a more varied range of student engagements to illustrate aspects of the building engagement. The excerpts which follow capture something of the overall environment of the students' building activities during the Invent a Machine project. Some of the variety of interactions and engagements that occurred are portrayed. Examples of how the students developed their individual understandings of what this task meant to them and how they enacted their understandings are described and interpreted from my perspective as a participant in the design and building engagements. The energy displayed in the transformation of the classroom environment to what may be metaphorically be described as an "organism" is one of the themes I am trying to capture in the portrayal of action-thought as it manifests itself in building activity in this chapter.

Getting Started on Inventing a Machine

This was the second day of the machine building project. Students were working in every corner of the classroom. Some situated their work space on tables, others chose a space on a side bench, and still others set up on the floor. Boards and sticks, string and tape and a hundred thousand pieces of LEGO emerged from hiding places all around the room. The noise was tremendous. Everyone, including me, was in motion. I was just finishing setting up my materials on a work table when I began hearing "Leo, we need you here." Similar requests were coming from several other directions.

At that moment, Len appeared by my side. He held up a pair of small wooden wheels and said "Do you think these can be glued together?" I rolled them in my hand for a second and then passed them back. "Sure" I smiled. "I just plugged in the hot glue gun so it should be ready in a couple of minutes. If you put some hot glue on the end of a popsicle stick it will probably be easier to get it just where you want it on your wheels." Len said "OK, thanks" and headed over to the hot glue gun station.

Keith came next. "Can you help me with these wheels. I want to put them on the end of these two motors ... you could use your drill." The drill was a little too difficult for most of the grade eight students to manage so I had announced to them that I would drill any holes they needed. I drilled holes in the center of each wheel. Keith mounted them on the axle of the motors. "Watch this" he said and went over to his table. He returned with a battery and a couple of banana clip connection wires. "Look at that sucker go" he said happily as he held the spinning motor up for me to see. "And they are centered on the axle real well too" he added. "See you can feel it like this." He held the motor gently between his thumb and forefinger. He seemed to consider this accomplishment to be something important and wanted me to know about it.

Rick suddenly appeared. "Can you come over to see our machine? ... we want to show you something." At their table, Rick and Colin demonstrated the lever part of their machine for me. Their lever consisted of a small plastic ruler balanced on top of a small metal block. They intended to launch a sugar cube from one end of the ruler into a coffee cup by dropping a weight onto the open end of the ruler. "Our main problem right now is accuracy" explained Colin. "We can't seem to get the sugar to go where we want." As they demonstrated the sugar launcher I noticed that their ruler went flying in the air every time along with the sugar because it was simply resting on the metal block. "Here is something you can try" I suggested. "Get a piece of wooden doweling from my work table, cut it shorter and try using it as a fulcrum instead of this block." Later, when I returned they were working on a different problem. They both looked up and insisted on showing me how their new lever worked. "It works great" explained Rick. "This rounded part (on the dowel) gets our ruler working better than it did with the block ... the sugar launches much better now."

Near the beginning of one class, Nancy appeared next to me. She patiently waited as I finished helping a group. "Mr. Leo, I need your help ... my partner isn't here and I can't do this by myself." She had both arms wrapped around a wooden board and a forlorn look on her face. "OK" I said, "I'll come over and have a look." She brightened immediately and we settled in at a spot on the floor she had chosen. A hot plate, a plastic dish, a chair and a two-pan balance were arranged there. "OK, here's my idea." She arranged the board so that one end poked through the hole in the back of the chair and the other end rested on the edge of the seat of the chair making a ramp. "Hold this" she demanded as she taped the top end of the board onto the chair. Then she positioned one pan of the two-pan balance under the bottom end of the ramp and placed the plastic dish on it. The hot plate was then positioned adjacent to the pan with the plastic dish. I had no idea what she was planning. She pulled a marble out of her pocket and said "See, the food will go down the ramp and land in the dish .... then the dish will slide over onto the stove and be cooked ... that's my idea." She picked up the dish, dropped it onto the hot plate and looked over at me with a satisfied expression on her face. "Whoo ... what an idea!" I exclaimed. "How will we get the dish to move over onto the stove?" Nancy shrugged her shoulders and turned the palms of her hands upward. "I have no idea. I'm just stuck ... I've got no idea where to go from here ... I want to pull it with a string but I don't know how."

Watching all of this had given me an idea about what could be done. "I've got an idea that just might work .... get some pulleys and clamps from the supply room and I'll get some stands and string." When we both returned I explained my idea. "Put your finger out ... OK, see ... it can be a pulley .... we can take the string and tie it to the dish and put it around a pulley to a hanging weight ... when the weight falls it will pull the dish over onto the hot plate." The string made a right angle as I pulled it around her finger. "That can work ... OK ... we can try that" Nancy exclaimed and began putting a clamp onto a stand. We worked together for several minutes arranging different combinations of clamps and pulleys. A student came over and asked for help. "Nancy, is it OK now?" "No problem" she smiled. She seemed pleased to be extending her thinking along a new path.

I am amazed by the ease with which most students enter into building engagements. The "Getting started on inventing a machine" presents interactions I had with students after spending only a few days in their classroom. These students were literally "chomping at the bit" to get started and they embraced me very quickly as a participant in their endeavors. This is not an insignificant point. Making things matters because it is an activity which allows both myself and students to work together with overlapping agendas. Students would approach me with ideas and questions and I tried to help them find ways to put those ideas and questions into action as best I could.

A researcher can only re-portray and re-present his/her experiences from a classroom research setting. The nature of those experiences depends on more than how the researcher considers himself/herself to be situated in the research environment involving young people. More importantly, it depends on how students perceive, interpret, and influence by their actions the researcher's role or way of being in the classroom. Engaging students as a collaborative assistant who was interested in how and what they were thinking enabled students to invite me into their workspaces. In addition, it enhanced my engagement with the larger classroom community. In both the Solar House and Invent a Machine projects, the community of students seems to have considered me to be interested in working with everyone in the classroom. I had research interactions with every student in both projects with Ms. B. and by the end of the Invent a Machine project, students were scheduling interview appointments with me, rather than the other way around.

This kind of research stance is not easy. It would seem that it requires the researcher to "wear two hats" at once, observer and participant-observer. However, I believe that an essential element of my research approach involved me in "wearing a third hat", namely that of participant. Experiencing the joy and satisfaction that emerges when a construction begins to take shape or is "put into motion" not only allows the researcher to "share" in some sense an experience with a student, it also allows the student to share his/her experience with the researcher. I believe that one outcome this research orientation was that it helped me to have meaningful conversations with students, especially in the final interviews. Research environments, such as those provided by the Solar House and Invent a Machine projects, that involve students in "making things" allowed me to wear the three research hats I have just described.

Acting-thinking "like a kid"

The following observation was made by Tim when talking to me about his involvement in the Invent a Machine project:

> **Tim**: Well, it's a bit different when you do something like this when you can actually make things. A lot of the other science activities you do, we have something that we're supposed to do ... we read from the textbook and we have to put .... to see who can dissolve salt or something ... **and here we can do whatever we want ... so like then I thought differently** ... I didn't think from the book and think of from like a professional scientist's kind of point of view. I was thinking of what a kid would like ... I was thinking more of people my age, of what people our age would like.

This provocative comment illustrates a point that many students made. Thinking in a building project was considered to be something that was more in tune with their own natural way of acting and doing which allows them to express themselves. No matter how well textbook activities are constructed they are still constructions which emerge from the adult world and are considered to be so by many students. Building is viewed to be a kind of thinking experience that is significantly different from other engagements in classroom science. Students are quite aware that in school science they are expected to learn how to think like an adult or act in accordance with goals relevant to an adult world. An expanded version of my interview with Tim, Mark and Keith is presented in Appendix C.

"Thinking like a kid" was reflected in the range of whimsical and creative constructions that students invented. Projects ranged from a "dog washing machine" (Figures 20 and 21) to a "cactus watering machine" (Figure 23) to a "fish scooping machine" (Appendix B) and a "candy sorting machine" (Figure 19). It is clear that there was not a strong connection between the titles students assigned to their inventions and the meanings normally attributed to those titles in the world outside the classroom. Rather, the meanings connected to the function of the various machines seemed to exist in an enacted space which was limited to the context of the classroom. Nevertheless, the scientific and technological challenges presented by an activity which asks students to develop and build a machine which incorporates and coordinates three simple machines is not a trivial task. Students approached the opportunity to extend their understanding of simple machines in an action-oriented context with energy and creativity.

The **dog washing machine** was built by Donna and Cathy. Washing Donna's dog was apparently quite an exciting experience because she and Cathy decided to invent their own version of it. In a sense they decided to re-enact their dog washing experiences in the context of their science project. It seems that when students are given an opportunity to create they tend to choose themes which are close to their experience (i.e. are a significant part of their world). Figure 20 shows an early sketch, drawn by Donna and Cathy just after the project began, of their idea for a dog washing machine.

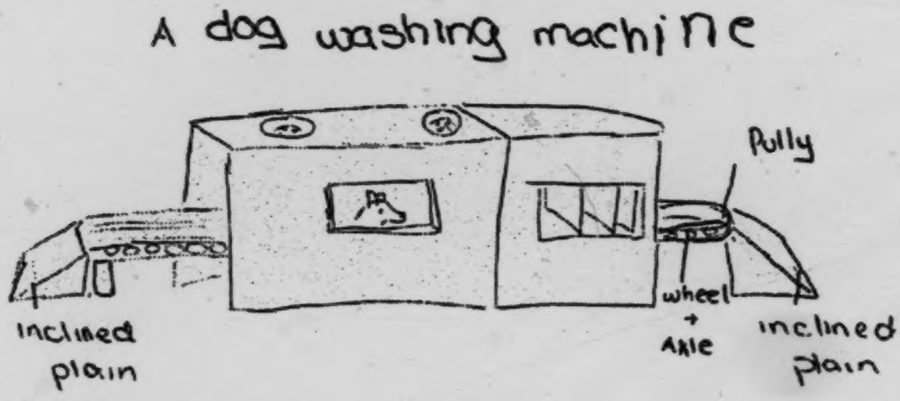


Figure 20: Donna's and Cathy's early sketch of their machine idea

Notice the difference between this depiction and the final illustration (Figure 21) Donna and Cathy created of their machine.

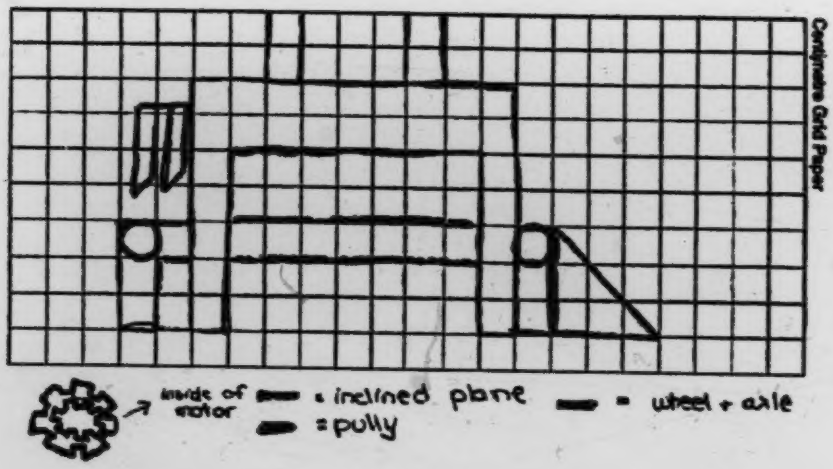


Figure 21: Donna's and Cathy's final illustration of their machine

The early sketch was drawn during the construction of the machine and seems to have played a significant role in the creative process in which the girls engaged to build their machine. This sketch was done on a worksheet provided by Ms. B. which she described to the students as a way to help them plan and develop their machines. In short, Donna and Cathy drew the early sketch for themselves.

The final illustration of the dog washing machine was made during the analysis component which followed the building sequence of the project. Ms. B. asked her students to draw a scale diagram of their machine on grid paper. The context of this drawing activity was clearly different from that of the earlier sketch. Now the thinking was more focused on the evaluation of their machine. Donna and Cathy did not draw the final illustration for themselves, it was drawn for Ms. B..

One would expect that students would be more able to communicate their understanding through a drawing activity near the end of a sequence of action-thought rather than near its beginning. This perspective is based on the constructivist notion that knowledge accumulates in a linear fashion. However, in a building project such as the Invent a Machine project important aspects of knowledge and knowledge development are embodied in the "doing actions" embedded in the project. When drawing is focused on putting thinking into action (i.e. early sketch) as opposed to reconstructing thinking which has occurred (i.e. final scale drawing) the kinds of drawings which result can be quite different. The final drawing indicates that the building project is over for the girls. The dog washing machine seems to be almost "shut down", stopped, ready for evaluation by the teacher. On the other hand, the initial sketch indicates that Donna and Cathy's thinking is "in motion". In other words, the initial sketch depicts the dog washing machine "in action" as it shows the dog in transit on its way through the machine.

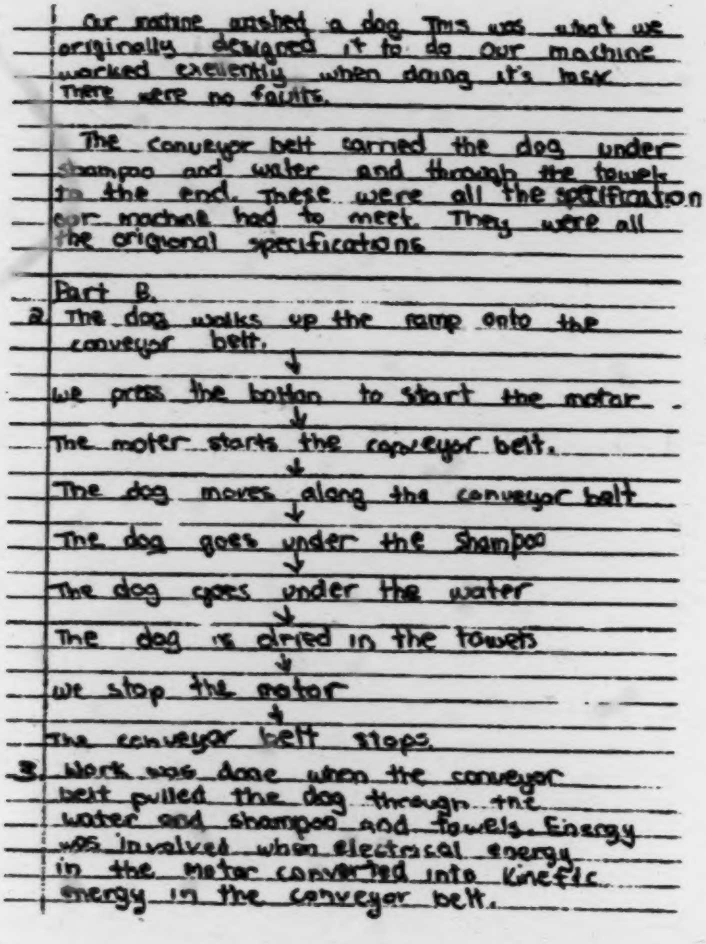
Donna and Cathy began their project in Donna's home where they found materials they considered appropriate for building. They used wood, nails, empty pop cans, and a long piece of used felt cloth to build a conveyor belt structure. It was about 1.5 meters long and 15 cm wide. The major technical problem which remained had to do with how to get the conveyor belt to move. At the beginning of the project they speculated that gravitational potential energy or water potential energy could be used to put the conveyor belt into motion. The initial sketch includes a pulley at one end of the conveyor belt which could be used to guide a falling weight that powered the conveyor belt.

Donna discovered a discarded hand-held mixer at home that had a rotary motion she could use to her advantage by mounting a short piece of wooden doweling inside it . The dowel provided a rotary drive shaft with enough friction to move the belt when it was placed inside one end of the conveyor belt. At first the conveyor belt did not move as well as Donna and Cathy wanted. They spent a long time (i.e. at least a couple of days) trying to solve this problem. After many trials, the girls finally innovated a design modification for the drive shaft which was satisfactory. This involved placing large beads of hardened "hot glue" along the surface of the wooden drive shaft. Donna and Cathy considered the motor drive to be a key development in the evolution of their machine. They even included an end view of the motor drive socket (which attached the wooden shaft to the motor) in their final scale diagram (Figure 21).

One of the forms of action-thought which Donna and Cathy enacted was especially interesting. Conversations about the motion of the conveyor belt would be accompanied by physical motions. For instance, Cathy used a small toy dog she had brought from home to demonstrate to Donna and to enact for herself the kind of motion she wanted the conveyor belt to have. She would playfully move the dog along the surface of the conveyor as she and Donna talked about how they wanted the belt to move. Playful action-thought seems to focus on putting thinking into motion and may be an important component of what students mean when they describe themselves to be "thinking like a kid".

Once the girls were satisfied that the conveyor belt was working properly they spent the remainder of their time developing and decorating a housing for the machine from a cardboard box. Two cut-out ice cream pails mounted on top of the housing provided portals for pouring soap and water into the "dog washing area". Strips of wash cloth material were hung inside the box in much the same fashion as one would find at a car wash.

Donna's and Cathy's written account, shown in Figure 22, includes a summary description, a flowchart, and a description of their understanding of the energy transformations for their machine.



1 Our machine washed a dog. This was what we originally designed it to do. Our machine worked exellently when doing it's task. There were no faults.

The conveyor belt carried the dog under shampoo and water and through the towels to the end. These were all the specification our machine had to meet. They were all the origional specifications

Part B.

2 The dog walks up the ramp onto the conveyor belt.
↓
we press the botton to start the motor.
↓
The moter starts the conveyor belt.
↓
The dog moves along the conveyor belt
↓
The dog goes under the shampoo
↓
The dog goes under the water
↓
The dog is dried in the towels
↓
we stop the motor
↓
The conveyor belt stops.

3. Work was done when the conveyor belt pulled the dog through the water and shampoo and towels. Energy was involved when electrical energy in the motor converted into Kinetic energy in the conveyer belt.

Figure 22: Donna's and Cathy's summary description, flowchart, and interpretation of how energy was transformed in their machine

The girls were very proud of their machine. It seemed like everyone in the class wanted to see the machine in motion and Cathy and Donna happily demonstrated it for many of their peers. Donna's and Cathy's written comments indicate their growing awareness of what it is possible for them to accomplish:

> We wouldn't change our design. We would of (sic) started building our machine sooner than we did. We liked the fact that our machine worked when we had to present it. The appearance of our machine is nice ... If we design a reasonable machine, it is possible for us to build it.

Clearly, Cathy and Donna considered themselves to have acted within an affordance space in which they contributed to the determination of what was reasonable and/or possible .

Figure 23 shows Andrea's and Janesta's sketch of their Cactus Watering machine.

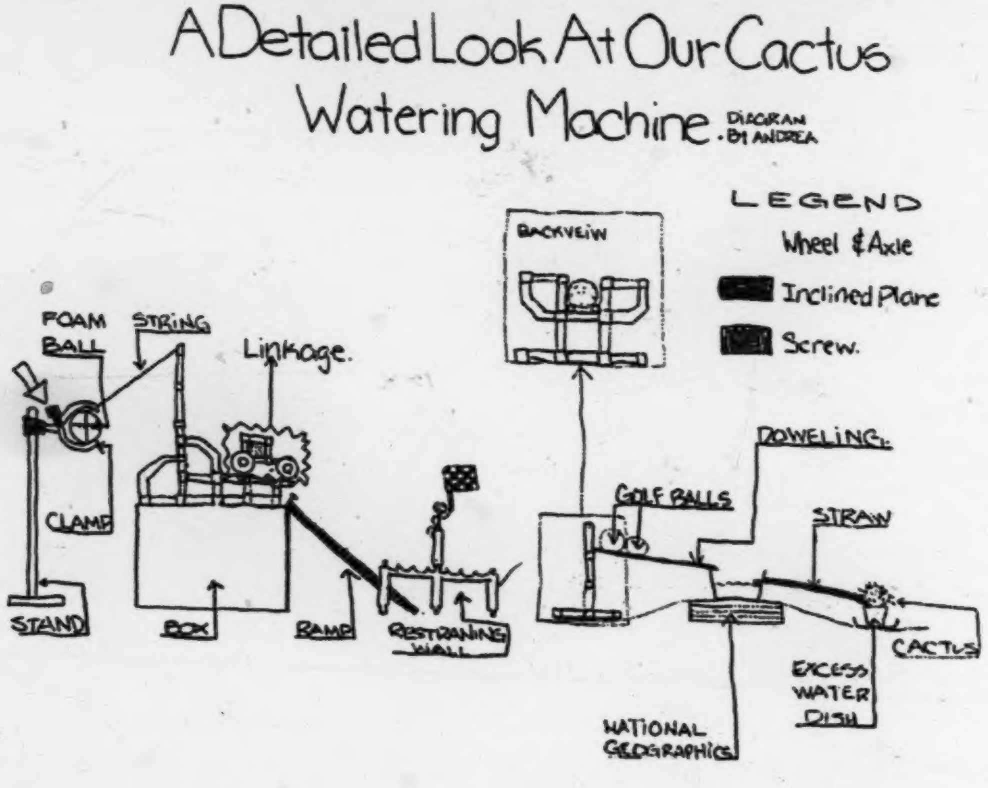

A Detailed Look At Our Cactus Watering Machine
DIAGRAM · BY ANDREA
LEGEND
Wheel & Axle
Inclined Plane
Screw.
BACKVEIW
FOAM BALL
STRING
Linkage.
CLAMP
STAND
BOX
RAMP
RESTRANING WALL
GOLF BALLS
DOWELING.
STRAW
CACTUS
EXCESS WATER DISH
NATIONAL GEOGRAPHICS

Figure 23: Andrea's and Janesta's sketch of their Cactus Watering machine

This was a large assembly which dominated one area of the classroom. Andrea's and Janesta's comments about their machine are presented in Appendix B.

Acting in a playful way can have a profound impact on the development of thinking. Andrea and Janesta did not set out to construct a cactus watering machine. Their original intent was to design a machine which polished "Doc Marten" shoes. This idea was abandoned as the two girls began to experiment with the plastic modular construction equipment they brought to class. They could not figure out how to use the equipment available to accomplish the shoe polishing task and so they began to play by connecting various pieces of the plastic modules together. Initially they built a car and a ramp. They were pleased with the initial developments and decided to build an additional ramp made out of two pieces of wooden doweling which held a golf ball. When the car rolled down its ramp it bumped the golf ball causing it to roll down its ramp. The girls experimented many times to perfect the sequence. One problem they encountered was that the golf ball would roll off the end of the table. This was a minor problem which they quickly solved by catching the ball in a small plastic dish. However, this simple solution enabled them to develop even more complexity in their machine. One of them suggested putting water into the plastic dish and when they noticed that the water level increased when the golf ball fell into the dish they decided to control this motion in their machine. They did this by inserting a straw through the side of the dish and using modeling clay to seal the hole. When the golf ball fell into the water the water level rose enough to cause a few drops of water to drip out of the end of the straw. The day after this development the girls brought a miniature cactus plant from home and placed it so that it received water from the straw. From this point forward they referred to their machine as the cactus watering machine.

The swinging pendulum (see Figure 23) was added at the end in order to meet the criteria of including three simple machines. The girls decided that a pendulum could be thought of as a kind of lever and added it to the ramp and wheel and axle systems they had already included.

One of the interesting things about the development of this machine was that it expanded in complexity and space as the girls generated new ideas. The rolling car had been the early focus of their machine. By the end of the development the girls referred to the car as a linkage (see Figure 23) in their machine. It had been subsumed by the emerging whole of the machine. It was not until the machine was actually considered to be working that it was given a name. Andrea and Janesta described what they learned about themselves by engaging in the project in the following way: "... we can work if we really try and that after a while things just 'mold together.'"

Just 'molding things together' is a good description of how action-thought coemerges with context. The girls saw everything they tried as a viable possibility during the construction of their machine. They simply found a way to incorporate it into the emerging machine. Andrea described it in the following way: "We didn't reach any limitations because if we came across a problem, we overcame the obstacle."

There was a great diversity of purpose in the various machines that students built. The fish scooping machine and the candy sorting machine are presented in Appendix B. Each reflects an inherent joy that emerges in a free flowing open building environment. A selection of other projects from the Invent a Machine project such as the Egg Cracking machine, and the Bell Ringing machine are also presented in Appendix B. Each project reveals the wide variety of possibilities which students explored. The section which follows describes how new possibilities for building can emerge out of the building process and the experience of making things real.

Creating possibilities by building

The generative nature of recursive action-thought was apparent in Mari's project. Mari's initial design was for a machine to deliver dry pet food into a dish. At the beginning of the project Mari described the function and specifications of her machine quite simply. On a worksheet, she wrote the following:

> It is going to be a feeder. It must pour the pet food into the bowl, etc..

Figure 24 presents Mari's working sketch drawn during the building process in which she depicts two possibilities for the ongoing evolution of her machine.

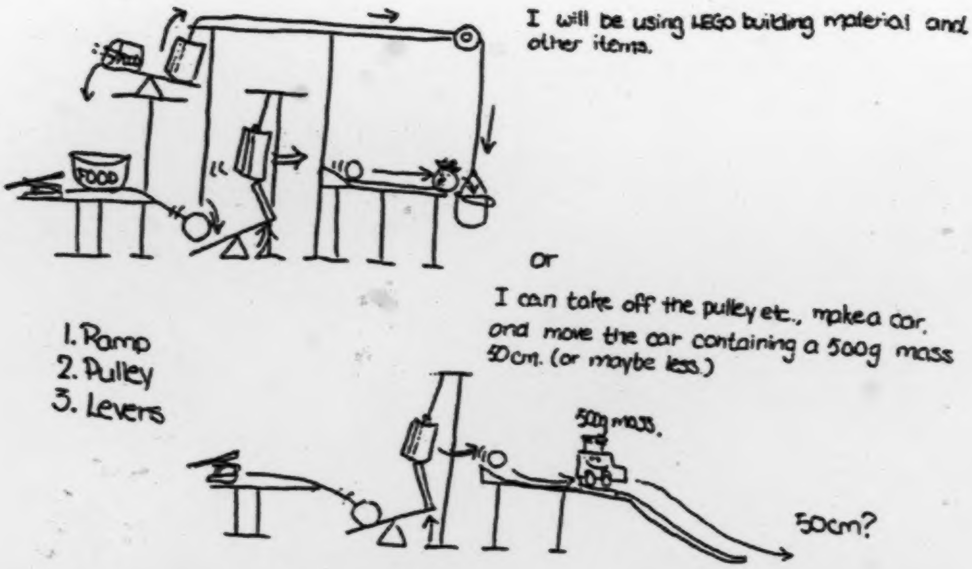

Food
FOOD
I will be using LEGO building material and other items.
or
I can take off the pulley etc., make a car, and move the car containing a 500g mass 50cm. (or maybe less.)
1. Ramp
2. Pulley
3. Levers
500g mass.
50cm?

Figure 24: Mari's working sketch depicting two possibilities for building

Mari chose to build her machine based on the ideas she depicts in the sketch shown at the top of Figure 24. She made a number of changes and enhancements. For instance, Mari used beans that she found in the storeroom instead of dry pet food as she developed her machine. She intended to replace the beans with dry pet food after the machine was working. However, it seems that the original purpose of her machine became less important as she focused on transforming a hypothetical machine into an actual machine. The beans became an integral part of the working machine and by the end of the project she was referring to her machine as a "bean dispenser" instead of a "pet food delivery" device. In addition, the starting sequence for her machine in which a falling ball and lever are used to initiate the pendulum was abandoned. She describes some of her decisions made during the development of her machine as follows:

> The pulley and the part where the beans dispense work well. I've decided not to use to the beginning half and I'm starting at the pendulum weight instead. I used a bigger ball to roll down the ramp. Therefore, it uses more force to push the 200g mass off the ramp edge.

Figure 25 shows Mari's final scale drawing of her bean dispensing machine.

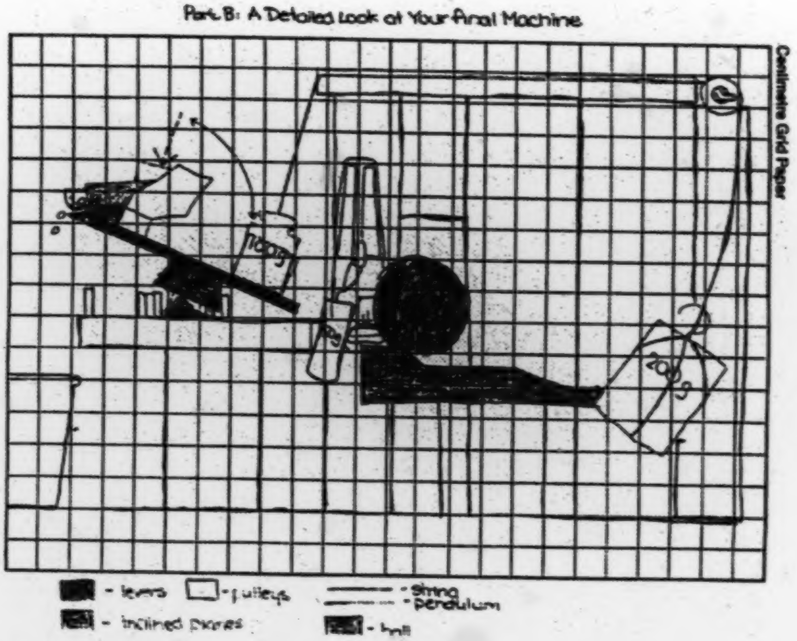

Part. B: A Detailed Look at Your Final Machine
Centimetre Grid Paper
100g
200g
- levers
- pulleys
- string
- pendulum
- inclined planes
- ball

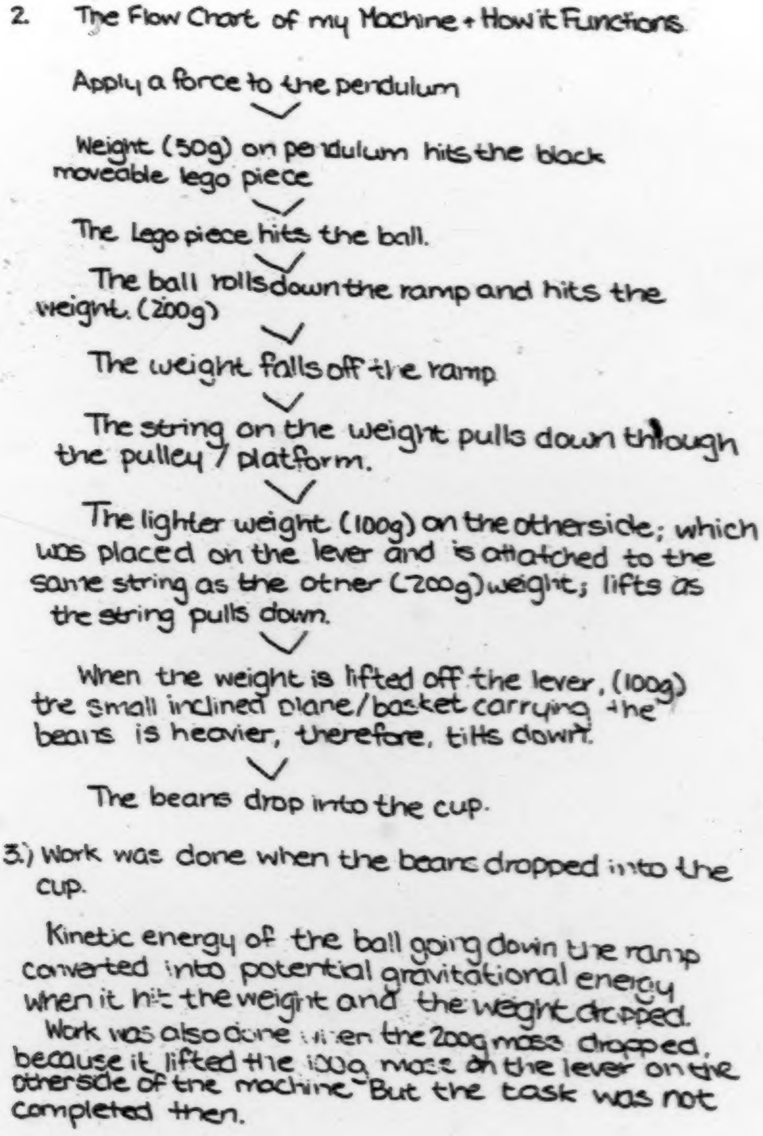
Figure 25: Mari's final scale drawing of her bean dispensing machine

Mari's written overview of her machine is as follows:

> The task of my simple machine is to dispense little beans into a cup. The way I was going to have the beans drop into a cup was originally the way I had it planned, but I changed parts of how the machine worked to do the task. I had problems with trying to make a fulcrum for a lever that moved easily but stayed in one position on the surface instead of pivoting around the place. I also had trouble trying to lift the 100g mass off the lever so that the beans could dispense, without using chemical energy. It took a lot of thinking, re-building, and re-creating to make my machine working, and it worked quite well once this was done.

Mari recognizes the cyclic and recursive nature of her thinking.

Figure 26 presents Mari's flowchart and description of energy relationships for her machine.



2. The Flow Chart of my Machine + How it Functions.

Apply a force to the pendulum

↓

Weight (50g) on pendulum hits the black moveable lego piece

↓

The Lego piece hits the ball.

↓

The ball rolls down the ramp and hits the weight. (200g)

↓

The weight falls off the ramp

↓

The string on the weight pulls down through the pulley / platform.

↓

The lighter weight (100g) on the otherside; which was placed on the lever and is attached to the same string as the other (200g) weight; lifts as the string pulls down.

↓

When the weight is lifted off the lever, (100g) the small inclined plane/basket carrying the beans is heavier, therefore, tilts down.

↓

The beans drop into the cup.

3.) Work was done when the beans dropped into the cup.

Kinetic energy of the ball going down the ramp converted into potential gravitational energy when it hit the weight and the weight dropped. Work was also done when the 200g mass dropped, because it lifted the 100g mass on the lever on the otherside of the machine. But the task was not completed then.

Figure 26: Mari's flowchart and description of energy transformations for her machine

Mari's reflections on the process in which she used to develop her machine are as follows:

> The lever where the 100g mass lifts and dispenses the beans is what I like most of all of my machine. I think this is probably because I worked the most on that part to try to make it work. I also liked my final idea of having a ball

> drop the 200g mass and lift the 100g mass on the other end because without this part functioning correctly, my machine would not be working.
>
> When this project was first given out, I thought that coming up with an idea for a machine was difficult. However, once I had my idea set up and my plan made, it was fun to make. I found it was really exciting when I got my machine to work. Overall, the machine was actually really simple to construct.
>
> While I was constructing my machine, I had to sometimes think of better ways of making my subsystems so they'd look attractive, or stay strong, or even function easier. Because we didn't have a really long time period to make our machines, I had to start recreating the other parts of it that were especially hard to make, so I could complete my machine in time.
>
> If we had an opportunity to make changes to our machines, I would take time to try and make it so that I could dispense the beans just by pressing on an object such as a button. I could try to make the machine bigger and stronger, and I would build it so that I have more room to hit the pendulum to get the machine working. If I were to design another machine, I would have an idea similar to the bean dispenser. I might make it and extended machine with more subsystems to go through to complete the task. Or, I can do the opposite, and take out some subsystems and experiment with motors instead of levers and ramps. I could make the bean dispenser work with batteries. Otherwise, I would just make up a new task and construct a new machine.
>
> While doing this experiment, I think I did quite well in staying on task and meeting the expectations. I discovered that building and constructing machines was fun, even if I had to think about the characteristics of simple machines and energy converting many times.

Perhaps the most compelling feature of Mari's description of her own process for engaging in action-thought is the number of possibilities which she considers to still be open for her to explore. This is an important characteristic of adequate conduct. Mari began the process with essentially two ideas for continued action-thought. These ideas dispersed into a wide array of potentialities. It is clear that Mari considers physical building as an important component of her understanding process.

The reader will recall Ian's comments with respect to his brother's **Mousetrap Car** project. Ian described a process of building where he consciously tried to keep as many possibilities open as he could. One way he did this was by leaving sections of his car uncut so that pieces of wood stuck out in an unfinished state. It was not until they tested the car that they were able to decide on an appropriate place to make their cuts. In fact Ian commented about how he noticed that other students had made decisions too soon and were constrained in an unproductive way by these actions.

The above two illustrations focus on the unfolding of possibilities in a progression where refinements and improvements are made to the same structure. The reader will recall

Keith's building engagements in which the unfolding of possibilities required a complete redesign of his machine. Indeed there were two preliminary machines which preceded the development of a final construction. Keith referred to this development process as being "multi-talented" in nature.

It works!: Expanding the world of significance

Nearly every student with whom I have interacted has described in one fashion or another the importance of making their idea work. What a student means when she says "it works" can be interpreted in different ways. For instance, one interpretation might be that she considers herself to have satisfied some external criteria (i.e. inclusion of three simple machines in the compound machine) which may arise out of teacher instructions or a competitive atmosphere among peers. A second, and perhaps more obvious, interpretation is that she is referring to the fact that her construction can be put in motion. While the first more socially oriented interpretation is worthy of consideration, I consider the second more personally oriented perspective to be more helpful in understanding aspects of the nature student thinking in building projects. For instance, in the Invent a Machine project I noticed that many students (e.g. Tim and Mark, Chapter 5) did not give much attention to the criteria of including three simple machines until just before they presented their machine to their peers and teacher. Other students (e.g. Keith, Chapter 5) seemed to become so caught up in the experiences they were creating for themselves that they never did give any consideration to external criteria . In other words, making a construction work involves an embodied form of thinking which is primarily personal in nature.

When a person builds something they create more than just a physical construction. They also shape the action space (i.e. affordance space) of which they and the construction they build are a part. In a sense the affordance space is an autopoietic entity which takes on a life of its own. An affordance space is a kind of action niche within a larger environment. A student in a classroom environment acts to give shape to the affordance space. The shape of the affordance space is dynamic in the sense that it includes everything that becomes significant for a student as they engage in action-thought. For instance, it may include materials, tools, talents, other persons, etc..

Ideas are not situated in any one place in an action niche or affordance space . Rather, they are distributed across the entire space. They are simultaneously a part of the setting and the persons acting in the setting. In a sense, an idea can be thought of as a kind of force field which permeates the affordance space and links its various components together. When an idea dynamically links the various components of an affordance space by putting them into motion then the salience or significance of the affordance space and the ideas which connect and shape it increases for the persons acting in that space. Putting an idea into motion involves putting the affordance space into motion.

In the Invent a Machine project, students were continually striving to create an action space which they could put into motion. As the cycles of failure and success and play-plan-act were repeatedly and recursively experienced the affordance space grew in significance. There was a palpable sense of joyful engagement as students worked to connect pieces and put them into motion. There seems to be a kind of desire to get simultaneously inside and outside. to experience the connection among things and the sense of euphoria which emerges from watching the ideas in motion from a distance.

In "Part C" of their analysis the students were asked to reflect on the building process by giving written responses to a series of questions (see Appendix B). Table 4 presents a selection of student responses to the following question from the analysis questionnaire: **What do you like about your completed project?**

Table 4

Student responses indicating what they like about building

My partner and I like our machine because of the process and how it works. We also like that it worked. - **Deani & Karisa**
We like the wind-up toy idea and we like the fact that it actually works. - **Shelly & Joan**
What I like about my completed project is that it works. Also I am proud of the effort I put into it and the time and thought. It was my very own idea and I thought it through with very little help. - **Sharon**
Kathy feels that we worked our hardest on this project and we met all the requirements, as well as we could, and she also feels that it was successful even though it didn't succeed during the presentation ... we both learned and enjoyed this project and we thought that it was more useful than one that we could have done from the book, one that would have an already designed procedure. - **Kathy & Anna**
We liked the originality and the idea that it works. Our machine has an unusual design that makes it special. - **Lorisa & Lavana**

What we liked about our completed project was that it works and it is an original idea. - **Andrea & Janesta**

What I liked the most about my completed project was how much it improved over the course of the week. - **Tim & Mark**

I guess the thing I liked most about my machine is that it worked. - **Ricardo**

Making something work is an invigorating experience. Many students commented that they considered "making it work" to be a significant component of their thinking. There is a sense of accomplishment associated with taking a complex task and developing it in an original way to a successful completion.

Table 5 presents a selection of student responses to the following question: **What strengths about yourself or selves did you discover or affirm while doing this project?** I have highlighted selected phrases within each response .

Table 5

Student responses indicating strengths they discovered about themselves

I found one of my strengths is **I'm good at making a plan in my head**. - **Brian**

We learned that **we can measure well** and that **we can make a real machine** if we put our minds to it.- **Deani & Karisa**

We discovered that **we can build a machine**, something neither of us could do before, and **we learned how to use a glue gun**. - **Sharlet & Kandy**

I discovered that **I have the patients (sic) to complete something** and make it work. - **Sharon**

We discovered that **we worked well together** and we got things done. **We both shared ideas** and worked on our problems that we faced when we were building our machine. - **Leena & Samantha**

I discovered that **I came up with fairly creative ideas**. I used my time well, which I didn't know if I would be able to do ... I ran into problems I found my way around them. I discoverd (sic) that this project is a lot harder than it sounds. - **Amy**

Our strength is that **we can perfect little parts of the machine after it was created**. -**Vance & Cameron**

... I thought that coming up with an idea for a machine was difficult. However, once I had my idea set up and my plan made, it was fun to make. I found **it was really exciting when I got my machine to work.** - **Mary**

As I came closer to finishing my machine I realized that **it wasn't an impossible task**. ... the activity became more and more enjoyable and when I finally finished, and the machine worked, I was very happy. - **Shelene**

We discovered that **if we try hard and cooperate, we can be very successful.** - **Lorisa & Lavana**

We found that **we are** patient, hardworking, agreeable **people, who** when they have their mind set on something they do all in their power to **make it a reality.** - **Kari & Anne**

Students discover important aspects about themselves in projects which require them to engage in independent and collaborative action-thought. The phrases highlighted above illustrate a series of themes. Students discover that it is possible for them to accomplish a complex task. Some students develop an expanded repertoire of skills. Other students discover how they can work successfully with a partner. A more extensive list of student comments is presented in Appendix B.

Table 6 presents a selection of student responses to the following question: **What parts of this project did you find easy? What parts did you find difficult?**

Table 6
Student responses indicating project parts they found easy and/or difficult

We found it easy to **imagine what we could do**, but it was difficult to realize if it were (sic) realistic. It was also **very difficult to actually put together (in real life) what was in our heads**, or in other words, actually make the machines. - **Linday & Sasha**

We found getting started and thinking of an idea for a machine hard to do at first. **Once we got started, we found it easier** to accomplish our work. - **Leena & Samantha**

The paper work was the easiest because it was just writing down what we wanted. **Building the actual machine was hardest** because we had to convert what we wrote down into a real object. - **Sharlet & Kandy**

We found **putting toghther (sic) the machine was easy, it's creating the machine that was hard.** - **Vance & Cameron**

> **The whole idea of our project was simple but making it work was difficult.** - Lorisa & Lavana
>
> **Getting the idea was easy, putting it together was the hard part.** - Andrea & Janesta

> I thougt (sic) that **the building of the machine was fairly easy compared to planning the design of the machine.** After I decided upon a procedure to build my machine, following the steps was easy. - **Shelene**

Most students describe building as the part of the project they found most difficult to accomplish. This is not particularly surprising given that this is what most of them spent the majority of their time doing. What is surprising is that so many students considered building to be such a novel activity in science given the action-oriented goals of the Alberta Junior High School curriculum. It seems that many students have little or no experience in working with materials and tools in order to accomplish a task. However, I was encouraged by the way students enthusiastically "threw' themselves into the building process. Furthermore, nearly every student who engaged in the building process was able to find a way to be successful. In other words, students not only discovered that building was difficult but also that it was possible for them to do.

There was a small group of students who had more extensive experience in managing a building project. Their comments generally focused on the process of coordinating and integrating various parts of a machine into a working unit as the part they found most difficult. In other words, even experienced builders find building difficult to accomplish.

An even smaller third group consisted of only a couple of individuals. These students commented that building was rather easy compared to finding an idea or planning a course of action. I am somewhat surprised by these comments because they do not mesh with my observations of the way these students developed their machines. I observed these students to engage in rather extensive physical manipulations before choosing a course of action. Perhaps they did not consider the early "playing around" sequences to constitute actual building. I leave this as an open question.

Table 7 presents a selection of student responses to the following question: **Did you find anything that was unexpected or surprising as you worked on this project? If so, please describe it.**

Table 7

Student responses describing unexpected aspects of their projects

We were really surprised when the machine was finished and especially surprised when we tested it and found out it worked, because at first we were thinking "Oh no! One week to build a machine? We're never going to finish." and "This is not going to work! We're going to fail." Then we came up with a machine that works and we were really happy. - **Sharlet & Kandy**

At the beginning I had no after thoughts about getting the machine to work. Gradually, as I worked, the more I realized that it was going to be harder and harder to get it to work. That is the only thing that worried me.- **Sharon**

We thought things were going to be easy to put together but they weren't as easy as they seemed. - **Lorisa & Lavana**

We didn't think that building a machine would be as hard as it is. - **Leena & Samantha**

Yes, a design is easier to draw than it is to make a machine and simple designes (sic) are the best for well working machines. - **Amy**

Students were genuinely surprised to discover that making their ideas actually happen was a difficult process. Many students seemed to enter a kind of ephemeral world of ideas where anything is possible when they first began thinking about a machine. As they began to engage in physical construction many students found they could visualize more clearly what possibilities they could and could not actualize. This required each one of them to consider their own strengths and weaknesses in relation to the things they wanted to make happen. In other words, as students became embodied in a problem their thinking became more complex and action-oriented. Some students began to use their imaginations differently as they continued to develop and improve their machines. Notions of the value of simplicity and elegance began to become significant in the worlds of action-thought which were created.

Emergence of an affordance space for action-thinking

Building things requires physical space. The nature of an effective building space is different than the areas which are normally allocated to students in science classrooms. secondary school classrooms are normally organized so that students occupy a rather "closed" space. By this I mean that once students are situated at their workspace (i.e. desk, laboratory bench, etc.) it is usually difficult for anyone other than the teacher to navigate a pathway through the space. Student workspace is typically organized in a way which encourages the students to remain "in place" as they work while the teacher moves through their space.

The layout of Ms. B's classroom provided a more "open" space for students to work. There were several island workspaces which allowed access from all directions. An open structure to the layout of classroom space is important to the development of thinking from three perspectives.

First, an open classroom workspace helps the students working inside the space because it allows them to "envelop" their project. Being able to interact with a building space in this way is a special affordance which encourages effective thinking in that space. I noticed in both the Solar house and Invent a Machine projects that many students seemed to prefer to work in a space in which they could easily move around the construction they were building. In fact some students even chose to establish a more open workspace by selecting an area of floor space or working in the Industrial Arts Technology classroom. How do the physical properties of a workspace influence the design of a construction? This is a question which I will not attempt to answer here in a complete way. However, it seems that students who successfully established an open working space seemed to generate larger constructions that include a larger number of ideas.

Second, an open classroom workspace can help other students to develop their own affordance spaces. My argument is that the affordance spaces that are most open in the physical sense are the ones which allow the largest number of social-cognitive connections and interactions to occur. Would Keith's thinking have developed in the same way (i.e. a series of prototype cars) if he had not had the opportunity to experience (e.g. visit and play with) other students' workspaces and the machines which emerged from those workspaces? Would Cathy's and Donna's understandings of the process they used to develop their dog washing machine been as meaningful to them if they did not have the opportunity to give several impromptu demonstrations during the development of their machine? Often, students are only given the opportunity to see and experience other students' work in its completed state (i.e. group presentation at the end of a project). This is not enough. When one engages a part of another person's affordance space (e.g. the person's workspace, their construction, or the person) and is able to "see" it as a trajectory rather than an endpoint of action-thought then the trajectory of one's own affordance space and the meanings connected to it is bound to be changed. Perhaps this kind of interaction is an occasion for action-thought which is both embodied and recursive. When one enacts or imagines oneself within an emerging physical space created by another, is one also re-enacting themselves within their own space, only from a new perspective? If so, then this may be a new way to consider reflective thinking. Reflection which emerges not only from a process where a learner reflects on their own actions within their own world of significance but also a process where a learner re-enacts themselves within another world of significance.

Third, an open classroom workspace allows the researcher/teacher more opportunity to act as a co-participant in a student's work. By acting as a collaborator in the development of effective action-thought a researcher/teacher is able to get a better sense of how a student experiences and constructs a world and their place within it. I will deal with this in more detail in Chapter 8 in the context of Ms. B.'s comments on her experiences with her students.

There is a public and a private quality to the nature of an affordance space. As a student works on a problem she/he develops a personal environment or niche for thinking by establishing a network of interacting affordances. This "space" is not restricted to the local boundaries established by a physical workspace but also includes a "toolkit" of experiences, skills, and other contexts. For example, in the Solar House project, several students (e.g. Clarence, Dan, Jill) established multiple workspaces, one in the science classroom, another in the IA Technology classroom, and yet another at home. In the Invent a Machine project, students brought their own personal "toolkits" of materials and equipment to the classroom which they then used in their own personal workspaces which were themselves embedded with a larger learning environment.

Making things matters because it allows ideas and thinking to be enacted in a world which includes the body but is easily separated from the body. In other words, a student can simultaneously get inside and outside a physical construction. One feels connected (i.e. structurally coupled) to a building space and yet the space is fluid enough that one can easily make changes without destroying the essence of the space. Maturana and Varela refer to this as the difference between organization and structure. There are many forms to the structure of the physical construction or the way persons interact with that construction but the organization of the building space remains the same.

Making things also matters because it allows people to be "in motion". Action-thought is not just is not just a fancy name for hands-on science activity. Action-thought involves creating and developing a world of significance by "feeling" your own motion as you move through an activity. Students were constantly engaged in purposive motion throughout the project. At the beginning a good deal of the movement was focused on establishing an affordance space. Materials were picked up, discarded and picked up again. Personal spaces for building, for storing items, and a space for moving through the various projects emerged. If an item wasn't nailed down it was potentially useful and if it wasn't inside someone else's personal space then it was considered to be a "free agent" available for use.

The "noticing" of commonplace things is an important form of thinking which is characteristic of thinking in building activity. As one engages in thinking by noticing, more things from the environment become significant as they are taken into a student's affordance space. In other words a person's environment grows in significance as they find new ways to take hold of it. As new components of the local environment become useful the significance of the surrounding context expands.

Being "in motion" is important because it has a generative effect on collaborative action-thought . An important quality of the Invent a Machine project was the amount of collaborative interaction which occurred between students.

Making things matters because building allows a person to re-present themselves in an embodied fashion. Many students are shy. They are not confident or aggressive enough to give voice to their ideas during classroom discussions and they do not write particularly well. Furthermore, once ideas are released in either spoken or written form the speaker essentially relinquishes control over those items. Spoken and written words may be attributed to a person but once they are evoked they cannot be easily re-covered or re-worked by a speaker. Making things allows a builder to communicate ideas in a more secure space. One is able to speak softly and enact loudly if one chooses. This gives action-thinking a plastic quality which is important. The organism is able to distribute ideas into a more public space and then re-cover them to a more private space. The persons never lose touch or control over that which is uncovered. This is not to say that the spread of an idea may be controlled. What is controlled is the embodied elements of that idea. Tony's way of using the building activity to reveal aspects of himself which became significant to other students in the classroom, especially Brian (described in Chapter 6) is an example of such a process (i.e. where significance and meaning emerge from action rather than from language).

The significance of knowledge is usually measured by its agreement with an established standard (i.e. its correctness). This gives knowledge a bipolar significance, it is either correct or incorrect, useful or not helpful. **Knowledge is embodied in processes of creating and developing when student make things.** These process allow for a broad spectrum of effective action and thus allow for a broadened spectrum of the significance of the knowledge which is developed in a building process.

Taking a risk: Extending an affordance space

So far in this chapter I have focused attention on student work from the Invent a Machine project. I will now extend and broaden the discussion about building by including selected portions of the Solar House project. The context of this building environment differed from that of the Invent a Machine project in a number of ways.

Both projects involved students from Ms. B.'s science classrooms in self-directed building challenges using simple tools and materials. In each case the building project was a culminating activity to a unit of work. In both projects, students were asked to enact their understandings of science concepts and ideas from the unit of work they had just completed by designing, constructing, and testing a device that accomplished a specific goal or set of goals.

The Solar House project was a culmination of a grade 9 unit on heat and energy. Prior to beginning the construction of their solar houses, students had completed a number of demonstrations on conduction, convection, and radiation. The reader may recall the episode from Chapter 4 in which Jill investigates the flow of heat in a convection box. As a precursor to what I refer to as the Solar House Project the students designed and tested a structure to preserve an ice cube. The Laura, Helen and Karla episode presented in Chapter 5 was a part of this engagement. As the culminating activity in this unit students were challenged to design and construct a box-like structure or one-room passive solar "house" that used the principles , procedures, and materials that they had encountered in the unit. This assignment differed from the Invent a Machine project in that a competitive component was included. Specific performance criteria involved measuring the area under the heating and cooling graph for the solar houses. Heating/cooling graphs which generated larger areas were judged to have outperformed those with smaller areas. The results of the areas measured under students heating/cooling graphs were tabulated and compared. Grade assignments were based on the rank ordering of the performance of the constructions.

The sample designs shown below in Figures 27 - 33 illustrate how four groups of students (Clarence, Dan and Tristen, Paul & Bernie, Jill) developed and represented their work in the Solar House project.

One way to distinguish engagement in a building activity is in the area of visibility and risk. In the Invent a Machine project the elements of visibility and risk were relatively subtle. Some students designed their projects to be visible and impressive to others. However, most students focused on the internal challenges of meeting the criteria that they had formulated. In contrast, the Solar House project environment was pervaded by a sense of competition. In their written analysis, Dan and Tristen, who have been introduced to the reader in the context of the Paper Towels task, describe their strategy in this environment as follows:

> We, the designers, decided to go out on a limb and try to use an active solar heating system in our house. We did this by heating water in a plastic tube coated with black construction paper, designed to absorb radiant heat energy from the light and re-emit it so as to heat the water in the tube.

My interviews with students revealed that there appear to be two approaches to designing and building in this sort of project. Some students try to distinguish themselves from their peers by including ideas that have not been explicitly discussed in the unit. These students describe their actions as "taking a risk". Other students focus on the ideas that are a part of the unit. While there are no new ideas incorporated the goal is to use their existing knowledge in as effective and sophisticated a way as possible. This often includes the imaginative use of materials and/or innovative features in design. Figure 27 presents Clarence's solar house.

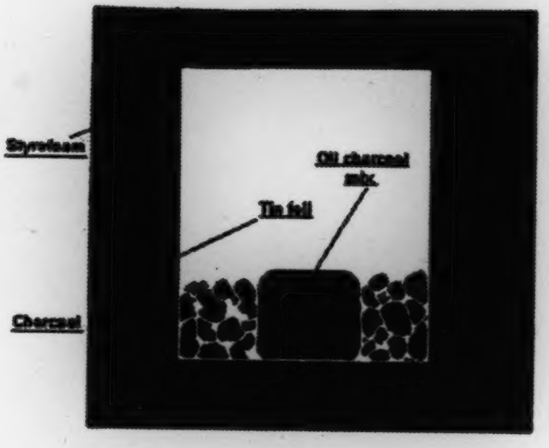


Figure 27: Clarence's drawing of his completed solar house

Students who describe their approach as "taking a risk" consider it to be more experimental in nature than approaches taken by other students who do not attempt to enhance the design of their construction by including new ideas. For example, in my conversation with Clarence he explained how he sees risk and experimental approach to be connected:

> **Leo**: Let's talk about some of the stuff that you have written for the solar house analysis. ... you say **"Well I liked the way that the finished project looked even though it looked like a piece of junk and I also like the experimental design of it. I was the only person in the class that used a liquid to gain the solar heat. This made me feel that my house was a true demonstration of the young imaginative mind at work."**
>
> **Leo**: ... you were the only person in the class to use a liquid.
>
> **Clarence:** Yeah, everyone else was using solids. It worked the way I planned it. ...
>
> **Leo**: What do you mean by imagination, the imaginative mind? ...
>
> **Clarence:** Well, I took credit for someone else's bit. I mean not really. No, not really. I mean, because I suggested that maybe I should use black oil for a liquid. OK, **I suggested that**. My Dad just suggested to use a liquid.
>
> **Leo**: How important do you think that is, to be imaginative in your work?
>
> **Clarence:** Well the thing about this one was that it was worth 20 per cent of the mark. So everyone else kind of stuck to the basics of using big rocks and black stuff inside because that's all we learned about. We hadn't learned about if liquids are good heat absorbers. We hadn't learned that so I just tried this. I realized that I could still get a good mark if I worked really hard on this **but I also wanted to try** ... because otherwise we're limited to only trying what she has taught us. You can't really be experimental since it's worth so

> much. That's one thing a lot of my friends came up to me and said, "If it wasn't worth so much, they'd learn a lot more." And if it wasn't so competitive either, if she had it not as a competition.
>
> **Leo:** OK, let's talk about that a little bit more then, about what it would be like if it was more experimental.
>
> **Clarence:** Well, people would think of better ideas, I'd say. I mean if they think more about it, they might come up with some new things that no one would expect them to come up with.
>
> **Leo:** Would you describe what you did in your solar house as being experimental?
>
> **Clarence:** Yeah, I mean I didn't originally expect it to work. I just wanted to see if it would. Yeah, so I took a risk.
>
> **Leo:** And that is a part of being experimental?
>
> **Clarence:** Yeah, take a risk. Lot's of people hate taking risks, so they don't take risks and they just use the stuff that we have already learned about.

Clarence's comments highlight a dilemma which many students encountered in the Solar House project. Building is a form of embodied thinking which inspires creativity and the creation of a personal space. When I asked Clarence about his written comments regarding "the young imaginative mind at work" he initially seemed embarrassed about describing his own thinking as imaginative. His father had played a role in helping him develop his idea. However, it is clear that Clarence considered his use of black oil to be his own original idea. This idea was his own unique contribution to the collaborative building space which emerged in Ms. B.'s classroom. He seems disappointed that some other students felt that they could not "take a risk" in the same way as he did. Clarence clearly values being able to engage in an action-thought space where exploring ideas is as important as making them work.

The design of Dan's and Tristen's solar house also reflects the spirit of Clarence's comments on risk. The boys seemed to be most viably engaged in the building project when they considered themselves to be "going out on a limb" in their approach.

Figure 28 presents Dan and Tristen's drawing of their solar house.

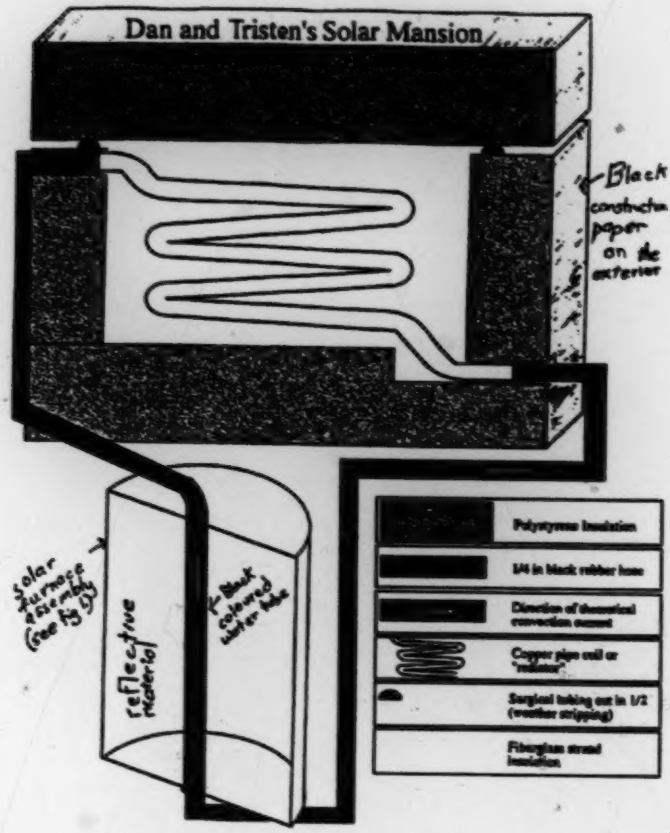

Dan and Tristen's Solar Mansion
Black construction paper on the exterior
solar furnace assembly (see fig 5)
reflective material
Black coloured water tube
Polystyrene Insulation
1/4 in black rubber hose
Direction of theoretical convection current
Copper pipe coil or "radiator"
Surgical tubing cut in 1/2 (weather stripping)
Fiberglass strand insulation

Figure 28: Dan's and Tristen's scale drawing of the solar house

The scale drawing does not adequately reflect the actual size of the construction which was very large compared to others. The boys seemed to celebrate this aspect of their construction by naming it "Dan and Tristen's Solar Mansion". Before embarking on an account of Dan and Tristen's approach to taking a risk in the Solar House project, I will describe how the theme of "taking a risk" emerged in the earlier the Ice Cube activity.

The first time I noticed Dan and Tristen taking a risk was in the Ice Cube activity. The Ice Cube activity is similar to the Solar House activity in that it challenges students to design, build, and test a device which accomplishes a goal. The goal was to design and build a small insulating box which reduced the rate of melting for an ice cube . Students evaluated the performance of their boxes by conducting a controlled test. Each group weighed their ice cube and sealed it inside its insulating box. After three hours the boxes were opened and the weight of the remaining ice cube was compared to its original weight. Part of students' grades for their performance in the activity were determined by the rank order of the performance of their insulating box in comparison to the others. The rest of their grade was based on Ms. B.'s assessment of written work which included an analysis of the ice cube box and responses to questions on the reflection worksheet (see Appendix B).

Dan and Tristen considered themselves to be intellectual leaders in Ms. B.'s class. Dan was quick to voice his opinion during class discussions and often challenged ideas put forward by other students and by the teacher. Tristen, while somewhat quieter, was also a keen participant in group discussions. Dan, Tristen, and Jill decided to work together on the ice cube activity. From the outset, Dan took charge of the enterprise. The idea he described to Tristen and Jill involved creating a near vacuum inside an extra thick, high density foam enclosure. The class had been learning about conduction and convection and Dan thought that reducing the number of air molecules surrounding the ice cube would reduce its rate of melting. Figure 29 presents their diagram of the structure they built.

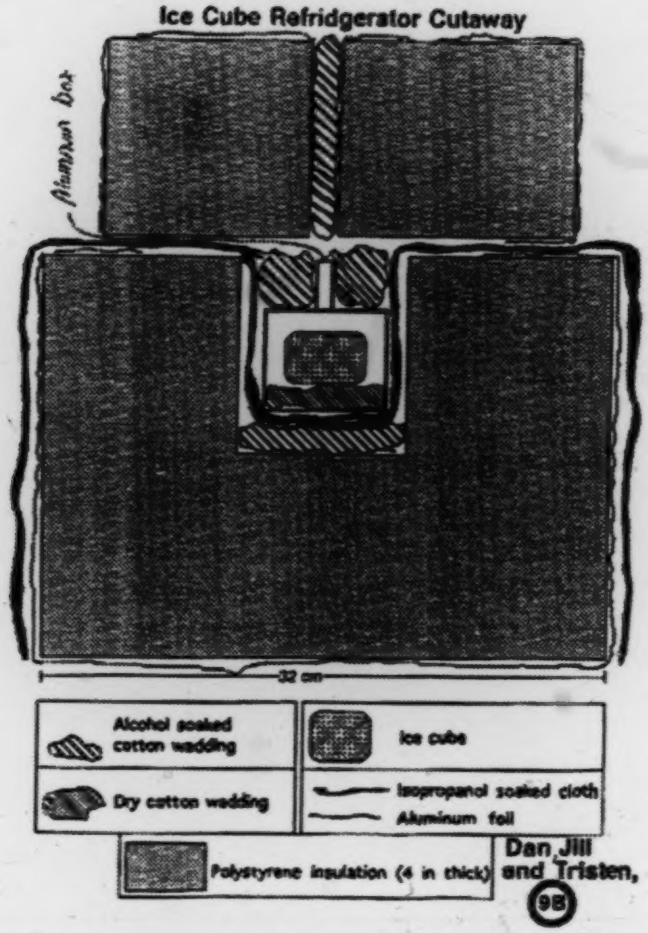

Ice Cube Refridgerator Cutaway
Aluminum box
32 cm
Alcohol soaked cotton wadding
Ice cube
Dry cotton wadding
Isopropanol soaked cloth
Aluminum foil
Polystyrene insulation (4 in thick)
Dan Jill and Tristen,
98

Figure 29: Dan's, Tristen's, and Jill's drawing of their Ice Cube box

Dan wanted to explore this idea because he felt that it extended and enhanced the heat transfer concepts that had been talked about during classroom discussions. He also felt that he was one of the few students in the class who was capable of accomplishing a task as complex as creating a vacuum. Creating a sophisticated solution to the ice cube challenge provided Dan with a way of maintaining his stature as a "leading thinker" among his classmates. It also provided Dan with a way to create a personal space in which to think independently.

Dan and Tristen were members of Mr. T.'s Industrial Arts Technology (IA Technology) class. He agreed to let them use materials and tools from the IA Technology classroom and to build their ice cube box there. Dan used sheet metal, extra thick high density polystyrene, duct tape, and a bicycle pump to construct an insulating box. The idea was to seal the ice cube in a vacuum inside a small airtight metal box which was encased inside a thick layer of styrofoam. The metal box was engineered with a small connecting pipe which stuck out of the layer of styrofoam. After the ice cube was fully sealed inside the apparatus Dan connected a special hand pump borrowed from IA Technology to evacuate air from inside the box. The whole apparatus, bicycle pump and all, was then left to sit for the three hour test.

Everyone was impressed with the design of Dan's ice cube box. It was much larger than the others and certainly appeared more complicated. It was the only one that required the owner to actually "do something" (i.e. pump out air) after the ice cube was inserted. Dan, Tristen, and Jill were very confident that their strategy would excel. Unfortunately, their ice cube box did not perform very well in the test. When it was opened all that was left was a puddle of water. Every other box outperformed it.

The essence of their approach remained the same in the Solar House project. Dan's analysis of his and Tristen's solar house provides a detailed description of the design, construction and testing of their invention (see Figure 28). The construction which they describe as an active solar heating design is presented detail in Appendix B. Dan and Tristen approached the design and building of their solar house in a way that was similar to the approach they used during the Ice Cube activity in a number of ways. Once again they took advantage of materials and equipment from the IA Technology classroom to construct specific parts of their device (i.e. the solar reflector - see Figure 28). Once again an original idea which they considered to be sophisticated was developed and given a chance to work. They were never sure it would work. Tristen commented to me privately at different times that he was quite sure that it would not work. However, they considered an approach in which they pushed their capabilities beyond their classroom learning to be the way to go.

In fact, "not working" is exactly what happened. When Dan and Tristen tested their solar house they found that the water did not cycle through the circulation system as they had hoped it would. Dan was perplexed as to why this occurred and, in frustration, picked the whole thing up and manually circulated the water through the hoses by tilting it back and forth. By the end of the testing period (i.e. at the end of the school day after approximately 300 minutes later) the inside temperature had risen only slightly. Dan was noticeably disappointed with this outcome and he continued to think about it after he arrived home a short time later. The following excerpt from Dan's written reflection describes his thinking at home:

> ... at about the 450 minute mark I cracked it open at home and a warm breeze rose out of it for a second. According to the graph it would have been approximately 29.5 degrees in there at the time.
>
> As stated above, I at first thought that we had struck out, and this deeply frustrated me. But when I found out that our heat loss rate was so low, I couldn't help but rejoice at its success, so much as to dance an embarrassingly silly jig in my kitchen after I examined the data.

Dan's observation at home seems to have played a significant role in the development of the understandings he considered to be most significant. His perception of the solar house was suddenly transformed from "not working" to "working". Dan describes an important dimension of his understanding in the following segment from his written reflection:

> I confirmed that I like doing detailed work, in respect to both the analysis and actual house, as well as putting a lot of thought into things. This may of (sic) been a problem because the first test of the house was the official test, so as far as I was concerned, it was all or nothing. While it didn't perform as well when heating up, it retained heat so efficiently that it more than compensated. From this I learned that waiting patiently for all the data to be in, instead of getting mad at the initial results, would be a good trait to adopt if I were to peruse (sic) a career as a scientist.
>
> But I think that after having recently discovered that my forte is thought, when on a tight schedule, perhaps I would make a good theoretical physicist.

It appears that Dan developed a deeper understanding of himself as a learner during the solar house project. Clearly Dan was a highly competitive student for whom success was mainly determined by the outcome of a project. However, while the approach of taking a risk may have compromised the grade he received, riding the emotional roller coaster of perceived success-failure-success seems to have influenced Dan to become more process oriented in his thinking. This aspect of Dan's thinking is reflected in the story-like quality of his written analysis.

An interesting feature of his account is how it is structured. Dan organized the account into three main headings which reflect a kind of journey of increasing depth into the problem. Dan begins with a heading titled "On the Surface ...". He then moves to "The Insides" and finally to "Testing It". In a sense, Dan's account describes a process of entering into and emerging from a world of significance. He comments in his written reflection that he was surprised at how easily he was able to construct his written analysis after such an intense engagement.

Dan and Tristen made an explicit attempt to change the context of both the Ice Cube and Solar House projects by adding design complexities which they felt would be original and unique. What understandings of viable processes for action-thought emerged from the Ice Cube activity for Dan and Tristen that could be enacted in the context of the Solar House task? In considering this question from a constructivist perspective, it would appear that they had not learned very much because they insisted on re-enacting an apparently unsuccessful strategy. However, viewed from an enactivist perspective, this question takes on an ontological dimension. Dan and Tristen seem to have wanted to learn about taking intellectual risks, not necessarily about the phenomenon of heat gain. Their appreciation of the experience of enacting risk in a building context was one theme which they continued to explore. Perhaps their motivation to think in this way was social in nature in that it involved maintaining status with their teacher and among their peers as creative and original thinkers. In my conversation with Dan and Tristen, they explained their motivation as follows:

> **Tristen**: ... in the ice-cube experiments. It didn't do so well.
>
> **Dan**: Because we went out on a limb and tried something.
>
> **Tristen**: I mean it was a risky idea. The same with the solar house. I mean we could have made something that was probably more, what do you call it, middle of the road. You know, basic. It probably would have worked fine but, you know, we wanted to try something new, that could work really well or that could totally fail.

I think there is a second more embodied factor that contributed to their choice of enacting a "risky idea". This factor involves the emotional and intellectual connection which emerges when one's own idea is put into motion. Did Dan and Tristen regard the Grade Ten Mousetrap Car project to be similar to the Grade Nine Ice Cube and Solar House projects? Once again they adopted what they considered to be a sophisticated and risky approach. Dan's and Tristen's first decision was to visit their grade nine Industrial Arts Technology teacher to borrow a "Fischer Teknik" building set. The "Fischer Technik" Building set was a large collection of high quality plastic and metal building components (e.g. wheels, gears, pulleys, tongue and groove blocks, rods, etc.) that can be essentially arranged in as many different configurations as a builder's imagination allows. Dan and Tristen both seemed to be impressed by the apparent sophistication of this building set and the fact that it was unlikely anyone else would use these materials in the Mousetrap Car project. However, it appears that they also recognized other advantages in using this kind of building material. During my visit to Dan's home (Tristen was also there), he and Tristen pointed out some of the advantages they saw in using this kind of building material to construct their Mousetrap Car. The following excerpt illustrates some of their thinking:

> **Leo**: Is that a big advantage of this "Fischer-Technik" building material?
>
> **Dan**: Yes, because we got to see our concepts running right "off the bat" ...
>
> **Tristen**: And we would have had to then be in a hurry to think of some other ideas.
>
> **Dan**: Exactly
>
> **Tristen**: ... I mean, like in the Solar House ... we couldn't assemble it and disassemble it. Like we sort of got an idea and then we tried it out. This thing we could test easy enough and we don't need like high powered lights or anything to test it.
>
> **Leo**: So if you were to compare what you did in the Solar House with what you did in this project, that notion of testing and repeated testing, is that a difference?
>
> **Tristen**: Yeah, I think that **is** a difference. ... I think we tested the Solar House more in our mind ... whereas this we can test physically. I mean right now Dan has already changed the thing (points to the Mousetrap Car that Dan has been making adjustments to throughout the interview).

Clearly, Dan and Tristen have made an important transition in the way they think about the nature of the process of design, building, and testing. The underlying theme of risk taking remains a central component of their approach to action-thought. However they have incorporated additional complexity in that their thinking has become more recursive in nature with the introduction of repeated testing and re-testing during the development of their car. This shift in approach seems to be connected to the diversity of design possibilities that the Fischer-Technik building materials provided and it allowed them to explore multiple design possibilities in rapid succession. Perhaps Dan's and Tristen's choice of modular building materials reflects a decision to reshape their building environment into one that was more plastic and fluid in nature, one that was more in tune with their own way of thinking than the building environment from the Solar House project. It is clear that they noticed a difference between the Mousetrap Car and the Solar House projects:

> **Tristen**: ... But it's also a different project though. Because I mean that other one, there was no way we could test to see if that thing worked until the very end.

> **Dan**: Yes, we didn't get the test going and we didn't get the re-test going. Like one of the main things on this one is that you get to show up (and) you get to try your thing. If it's screwed then you get a chance to fix it. You know, share ideas with the people, talk to the teacher.

It appears that Dan's and Tristen's experiences in their previous building projects had contributed to a significant change in their understanding of **how** to engage in action-thought. The following excerpt from my interview at Dan's home illustrates one dimension of their thinking that had changed:

> **Leo**: Have any of the projects you did last year influenced ... the way your thinking was going on this project?
>
> **Dan**: ... I learned ... that good engineering is based on making something that is as simple as possible. The more complex you make it the more liable it is to just screw up and not do what you want it to. So ideally you want to want to just make something ... as absolutely simple as is possible. And I mean you can mess around with aesthetics and things afterwards, but getting something simple that works is the main thing. I can say the main influence in basically everything that I have done since I have thought about that was "the best thing is the simplest thing". So I mean that was foremost on my mind in terms of philosophy while we were putting this thing together.
>
> **Tristen**: Well I have thought about that pretty well, too, especially with the Solar House. That didn't work so well and that was complicated.

Clearly, Dan and Tristen had reconceptualized their approach to this kind of project in the intervening year. An emphasis on complexity of design was now replaced by an emphasis on simplicity. We typically confine of assessment of outcomes to short term learnings. The question of how our learning and experiences are restructured to yield increased competency in our thinking with respect to subsequent more complex tasks seems to be an open question. In Dan and Tristen's case it seems that their prior experiences in the Ice Cube and Solar House projects were connected to the development of a revised approach in the Mousetrap Car project . It may be that the emergence of complex understandings from embodied building engagements may requires an extended time scale and/or a significant change in context.

In my final interview with Dan some eighteen months later, he noted the importance of a longer term view in the development of a meta-level understanding of how to engage in complex action-thought:

> **Leo**: One of the themes that you and Tristen described as your way of doing ... the Solar House project ... was the idea of taking a risk, of wanting to add something new into the project that perhaps had not been included in what you had been learning class.

> **Dan**: Well that's the magical part of learning, ... when you can take something that somebody has told you and then add something yourself to it so that at the end of the day you're left with way more than you started with and sometimes the only way to get that is to take a chance. Is to vary something, do something differently, step out on a limb, and see if something works and if it doesn't, you've learned something and if it does, you've learned something ... equally valuable, maybe more valuable, maybe less valuable. But ... then what that does, is that causes you to ask more questions, and that's what the game is all about.
>
> **Leo**: ... You and Tristen have continued to work together for quite some time now. Have you noticed any progression in the way that the two of you think and do things when you work together on building projects?
>
> **Dan**: Well, I've found that I still like to take risks and try things new but I'm a little more conservative now in the process of just trying things. Instead of just whacking things together and trying them, I'm being a little more careful now with keeping track of what I'm doing and keeping track of the subtle variations and results that we're finding when we're fooling around with new things that work or don't work. And that stretches beyond just science, that goes into everything I do, I guess. There's a little more of a process, a little more something concrete behind ... (pause) something methodical now, is what I'm finding, more of a method, more of a restraint. I guess you lose some of the excitement then, but you get more out of it at the end of the day.

Determining what a student learns in an engagement such as the Solar House project is problematic. For instance, it appeared to Ms. B. and to me that Dan did not learn how to re-shape his approach in the Solar House project after the difficulties he encountered in the Ice Cube activity. However, when I observed Dan engage in the Mousetrap Car building project the following year (his first opportunity to re-engage in an open-ended project), I noticed a rather dramatic shift in his approach and in the level of confidence he had in his ability to be successful in the challenge.

The complexity that Dan added to his design and building approach involved including extensive testing and re-testing of the Mousetrap Car as it was being developed. For instance, during my visit to his home during the Christmas break I observed Dan revise the design of his car several times. Dan's father commented to me that he was amazed by the number of incarnations that the car had undergone. In short, Dan's approach had become more recursive in nature. More importantly, it appears that Dan was becoming more self-aware of the recursive nature of his approach to action-thinking and the role it played in the development of his understanding. This point is supported by Dan's comment from my final interview with him in which he talks about his newly formed computer drafting company:

> **Leo**: What I am asking is ... the skills that you bring to this company with your partner ... have they been developed in any way by your experiences in more extended building projects in the past?
>
> **Dan**: Well, the process of design for me has changed. I used to draw things, when I was sketching, with pen but now it's pencil just because the concept of setting anything in stone early in the process ... that doesn't work for me anymore, that doesn't do anything for me anymore. That's one of the things that the computer has allowed me to do now, moving from the pencil to the sort of ultimate erasable realm, the computer. So I can just "select" areas and "drag" them around. I can flip things around, I can really have the different dimensions of something at my fingertips right there ... then we can go in there and we can look at it and we can say "No, that doesn't work" and go back and change it again and **it's a sort of a never ending process, the same way as everything that we have done before with the projects, the building projects**.

Dan returned to the theme of recursion in his maturing understanding of his approach to action-thought processes:

> **Leo**: Aside from the specific concept things that you learned in something like the solar house project or the mousetrap car project or this more recent catapult project, ... are there other things that you learn over time by participating in those kinds of projects?
>
> **Dan**: ... That's something, you know, a step in the process which became more and more apparently **useful** as we went through it. Because **if** we had gone back and we had tried some different things with the solar house before we had ... whacked it together, there are a couple of things in retrospect we might have done differently. And it goes that way with every project, ... things that we could have done differently.

Dan elaborates on this theme as follows:

> **Dan**: And that was one of the things about our learning experiences ... with those projects. ... Afterwards, most of the people just threw their things away. A lot of them are just sitting in the back physics room in the school or in the basement or they're just in a "dumpster". Some people threw theirs on the Calgary Trail and watched a truck run over it ... that was the Mousetrap Car. They were disappointed with the performance of their car so they threw it onto the major road. (It was a pathetic car actually, I must admit.)
>
> But that was one of the things that we did differently. ... **We took the mousetrap car apart (and), as we were taking it apart, we were asking ourselves "If we had done this differently ...?"** And when we had the catapult, after we were done and we had seen what the other people had done, we were like "Oh yes! That different bit of structural reinforcing there allowed their thing to flex a lot less ..." and so on. We just were able to analyze and wonder about these things ...

Dan is talking about an emerging capability to visualize new pathways for action-thought. He has moved from a consideration of the physical reworking of the project to a consideration of the role that viable action-thought processes play in the development of understanding. He recognizes this change as a significant step in his cognitive maturation:

> **Dan**: ... I think it was a major step to be even asking the questions after the fact because that demonstrated to us, and to the teacher, and to some of the other people in the class who we were talking to about the projects, that the experience was more than just putting the thing together and doing the trials and then throwing it away. That **asking the questions about what you could have done better, how you would have changed it, (and) how you would have done things differently is another integral part of the learning experience and the importance of that is becoming increasingly apparent to me over the years.**

Perhaps the most significant kind of learning which occurs for a student in an enactive setting has to do with the personal re-shaping of ways of being engaged in viable or effective action-thought. Learning about one's own **way of being** seems to require a series of re-experiences over a rather extended time scale. Considered in retrospect, Dan seems to have learned a great deal from his experiences in the Ice Cube and Solar House activities. However, the nature of what he had learned did not become apparent until he re-visited a similar problem setting in the Mousetrap Car project. He continued to use and develop his new insights into his action-thought process in a grade eleven physics building project and in his undertaking of a personal project in which he and a friend formed a computer drafting business.

Dan referred to his subsequent experiences in building projects and computer design as a "never ending process" which was "the same ... as everything that we have done before with the ... building projects." In other words, over the four years that I interacted with Dan he enacted processes of "building" or "making things" in several different worlds or contexts, both physical (i.e. Mousetrap Car) and virtual (e.g. Computer Aided Design). This suggests that perhaps the most significant thing that emerged for Dan from his engagements with each of these enacted worlds was the growing complexity his understanding of what kinds of action-thought he could enact in future. Dan's cognitive approach seems to have evolved from one that focused on using ontological and epistemological pathways already traveled as a basis to construct experience in the present to one that focused on using experiences of the present to anticipate potential ontological and epistemological pathways which have yet to be explored. This cognitive shift seems to have enhanced the viability of his process for developing understanding. Perhaps such a cognitive shift requires more than adequate time to reflect on prior experience. It may be the case that a shift toward anticipatory action-thought may require that a person be concurrently engaged in action-thought.

The quote at the beginning of this chapter is an excerpt from my final interview with Dan. On the surface, Dan's comment seems to contradict a central of this study hypothesis (i.e. that action-thought is a form of understanding). Let me now re-present this excerpt from my interview with Dan in a somewhat broader context:

> **Leo**: Do you think you will continue to build things? Would you say that you are building something in another sense when you are doing the CAD (Computer Aided Design) work and will you continue to do physical building in the future?
>
> **Dan**: The physical building is an extension of the real building which is in here (points to head) and that I'll always be doing, I know that. I'll stop when I'm dead. Building things physically is part of the process and building things mentally is the process, period.

Clearly, Dan considers the process of action-thought to be central to his own way of knowing. The process of physical building is now embodied for Dan. Building has become a part of Dan's approach to thinking and has allowed him to create a new world of significance.

Creating worlds of significance

I will close this chapter with a brief account of how a personal world of significance was created within two other building projects. It seems that the significance which emerged from the different worlds created by students during the Solar House and Invent a Machine projects was highly contextual. While it may appear on surface that most students developed a common understanding of the science concepts being taught, what students considered to be most important was often quite different. For example, Bernie and Paul describe the problem as they interpret it:

> In creating our solar home there were several "key issues" that had to be answered but the 2 most important questions were: "How do we get maximum heat gain; how do we keep our heat in" and this is how we answered our question.

On the other hand, Jill described that her understanding of the nature of the problem changed over the course of the project. In the reflections worksheet she wrote:

> I found it difficult to understand the primary goal when heating. I didn't know what I was supposed to achieve (e.g. highest temperature and/or retains heat longest).

However, in her written analysis (Appendix B) she presents the problem as something that she now understands. At the top of her analysis she wrote the following description of the problem as she saw it:

> PROBLEM: To build a "house" which has a maximum solar gain and retention, AND which reduces/prevents heat loss.

Notice how Jill has capitalized the word "and", apparently for emphasis.

Creating and expanding a world of significance can be successfully accomplished by students in different ways. For instance, the nature of inventive process for Bernie and Paul displayed similarities and differences from the process developed by Jill. Figure 30 presents Bernie's and Paul's drawing of their solar house.

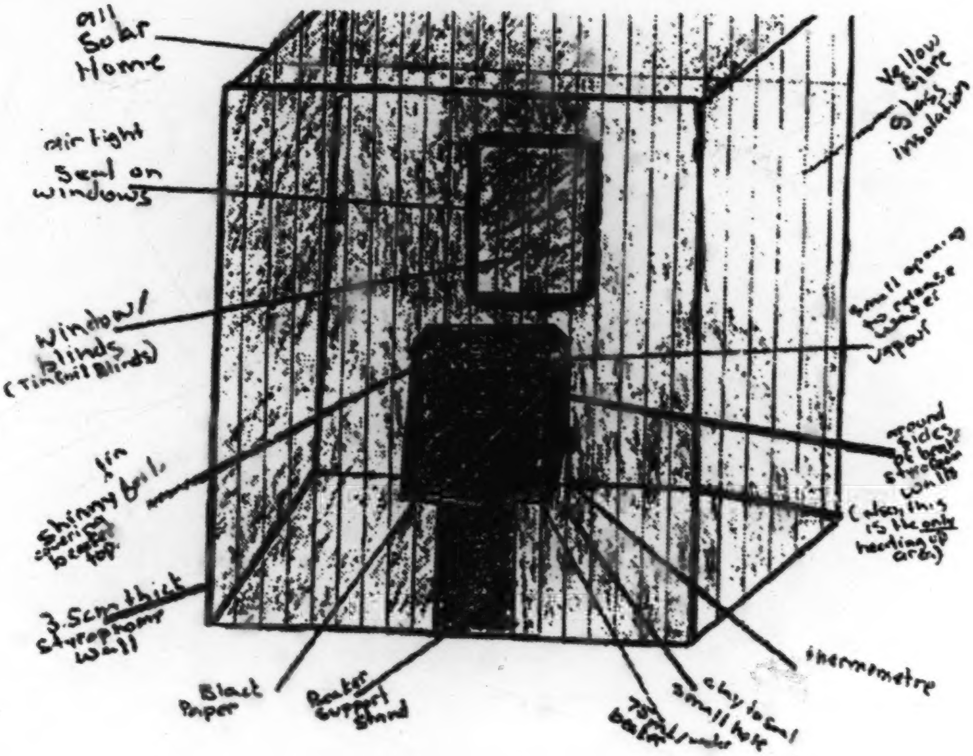

all Solar Home
air tight Seal on windows
Window/ blinds (Tinfoil Blinds)
tin Shinny foil stering beaker top
3.5cm thick Styrophome Wall
Black Paper
Beaker Support Stand
75ml/water beaker
Small hole
clay to seal
thermometre
around sides of beaker styrofoam walls (also this is the only heating up area)
Small opening to release water vapour
Yellow fibre glass insolation

Figure 30: Bernie's and Paul's drawing of their solar house

Bernie and Paul's written account is presented in Appendix B. The excerpt from this account which follows describes how they dealt with their problem.

> To summarize what happened, the sun's ray entered through the plastic window (radiation) and hit the black beaker sitting on the stand in front of the window. The black paper conducted the heat to the water, warming it up through a little spoute (sic) warm vapours escaped and warmed the tiny living (heated area) space. To keep in heat, blinds were placed in the window and the insulation kept in the heat.

Figure 31 presents the table of data that Bernie and Paul collected during the test.

start	10:50	temp.	25°C	3:15	23°C
End	11:20		45°C	End	23°C
	1:05		34°C		

Figure 31: Data recorded by Bernie and Paul during the Solar House test

Figure 32 presents the heating/cooling graph Bernie and Paul drew.

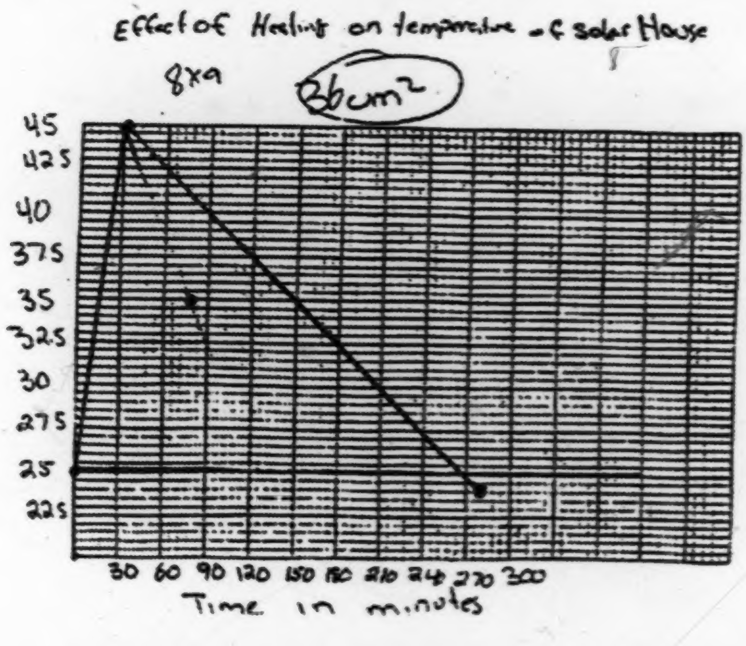


Figure 32: Heating/cooling graph constructed by Bernie and Paul

The ideas Bernie and Paul used in designing and constructing their solar house were essentially the same as the ones they were learning in class. The role materials such as black paper, tin foil, water and styrofoam play in heat gain/loss were all things that they had dealt with in class. Nonetheless, they still considered their approach to be inventive and original. The importance Bernie and Paul attached to a novel component - i.e. using a sports card cover for the window of their house highlights the central role it played in the understandings that emerged for them during the project. In other words, Bernie and Paul created and expanded their world of significance by enacting their ability to build and innovate the building process. Table 8 presents the responses that the boys wrote to selected questions from the analysis (see Appendix B).

Table 8

Bernie and Paul's responses to the solar house project focus questions

What do you like about your completed project?

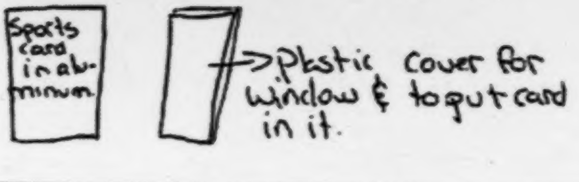
In doing our project, I was really proud in how it turned out. I thought we put a great effort to make the house as successful as it was. I liked the originality of our window + blinds on it. I didn't see anyone else use a sports card cover as a window. I think it made the house a success because a sports card could fit in the slot, + it helped retain heat as we put aluminum around the card. I think that we accomplished more than we wanted too, gaining as much heat as we had, + the amount of time we retained the heat gain.

What strengths about yourselves did you discover or affirm while doing this project?

In doing the constructions of the house, I discovered that the learnings (sic) I made in class directly affected the results of our experiment. We learned how to insulate a house and use specific materials to retain maximum heat gain. I also affirmed that working in pairs also helps the house to be the best. This is so, because 2 minds are better than 1, and this way, we could compare 2 factors and research which ways are best to make the house.

Did you find anything that was unexpected or surprising to you as you worked on this project? If so, please describe it.

There was only 1 real surprise that we stumbled on. When we couldn't cut a glass window out correctly we searched for a new window. We found a hard, plastic sports card cover. What this did, enabled sunlight to enter through the window and when we had to shut off the light, we put a sports card wrapped in aluminum paper (to reflect heat back into the house) shinny side down and placed it through the cover.


Sports card in alu-minum
->plstic cover for window & to put card in it.

It was surprising because I think the aluminum reflected heat back into the house & the window enabled a great amount of radiant energy to enter the house.

How well did you meet your own expectations in completing this project?

After having completed our project, I was quite surprised at the results. I was interested in our heat gain because I didn't expect to have a 25 C heat gain. I mean, to travel through a window, a cm wide black beaker, and to heat 25 mm of water is amazing. I never did expect a great gain. I was a little shocked at the rate we lost the heat. I thought that we had a compleate (sic) closed system (air tight) and the materials we used (styrofoam, fibreglass insolation (sic), and blinds on the window) would definately (sic) retain the heat for a long period of time. Unfortunately, we weren't successful enough. I just hope that next time we could fix up our house and explore all our fields of errors.

Clearly the innovation of incorporating something they had brought from their world outside the classroom into their project was of central importance to the development of their understanding. Incorporating novel materials was something that Jill also did in the construction of her solar house. Figure 33 presents Jill's drawing of her solar house.

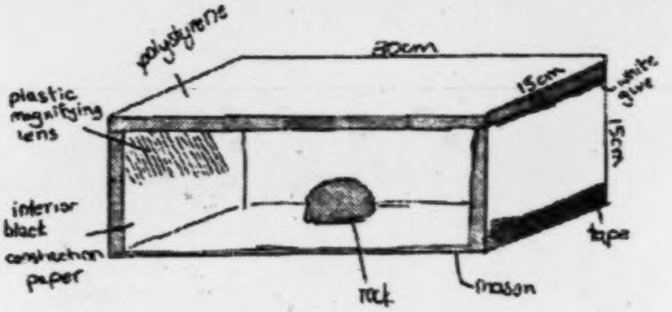


Figure 33: Jill's drawing of her solar house

For Jill, two components of her house were innovations on her part. These were the use of a rock as a material to retain heat and a plastic magnifying glass to focus heat on the rock. These ideas were not a part of the classroom discussions leading up to the Solar House project. These were innovations directly connected to the scientific ideas being learned in the unit on heat and energy. In her written reflections Jill wrote:

> My project is very original. I applied many concepts and the results were, in my mind, successful. I was creative in regards to focusing incoming light onto the rock, which would distribute heat equally. I am happy that I thought out and executed my design carefully.

There are multiple ways that students create and maintain a world of significance when they are building things. Building is a visible activity that is physically experienced on both individual and a collective levels . When students build their own constructions and observe and experience the process as it emerges around them they develop a more complex understanding of themselves as learners and of their capabilities to be successful in carrying through a complex and extended task. The actual structures created are not an end in themselves. Most students realize this. Rather, the building process is a pathway to further engagement in complex action-thought and the experience of how to engage in this action-thought. The understanding that "**I can do this and I know I can do more**" describes an important outcome of the building process. Being able to envisage oneself in future action is a powerful motivation and incentive for the development of future action.

Chapter 8: An Enactive Learning/Teaching Classroom

> *... I realized the futility of trying to structure process, that process doesn't happen in a linear way. I mean it's just kind of like an army marching through a swamp tackling all things on all fronts at once. (Bridget, 1995)*

In the foregoing three chapters I have portrayed the development of understanding in the context of enactive classroom environments in ways that focus on the individual student or small groups of students. I will now discuss the complex social-cognitive environment of an enactive learning/teaching classroom. The classroom setting is not just a backdrop to student action-thought. It dynamically evolves as the people within it act to shape it. I will describe some of the emerging characteristics of the learning/teaching environments in which I conducted my inquiries. The teacher perspective in its interaction with the student actions will be viewed from the vantage point of my participation in this environment.

Developing a classroom research approach

The nature of my participation as a researcher developed during the course of my involvements with Ms. B.'s classes from that of essentially an observer and interviewer to that of an actively engaged resource person.

Entering a classroom community is not a simple task. My research engagements with Ms. B. and her students began with the **Solar House** project. During my early involvements in her classroom I tended to remain on the perimeter and observe the students as they worked. I was present every day and soon certain students began to become visible to me as individuals (As part of my research strategy I did not ask for seating plans or student grades). An essential component of my approach was to wait for students to approach me, which they did. An early incident involved a boy who was investigating viscosity of various liquids by depressing the plunger on a syringe containing each of the liquids in turn. After completing the assigned task the student continued playing with the syringe and noticed the formation of a cloud within the enclosure. He approached me rather than Ms. B. (who was occupied elsewhere) and showed me this discovery. The action constituted a "breakthrough" in that other students began showing me things they considered significant. These invitations from students encouraged me to get out of my seat and become a more active participant in the classroom community. Eventually, I was invited by Ms. B. and the students to take part in the classroom discussions and demonstrations. On one occasion I conducted a demonstration of some of the properties of liquid nitrogen which generated considerable interest and excitement. From that point on I was considered to be a member of the classroom community.

Ms. B. frequently gave her students opportunities to do the many "hands-on" activities that are a part of the grade nine curriculum. This was helpful to me as a researcher because the increased level of activity during these sessions provided me with opportunities to interact with individual students as they worked. However, I was still acting in a mindset which situated me as an observer engaging students in conversation about their ideas. Students seemed pleased to pause and explain what they are doing as they worked. I entered a second and deeper level of engagement in the course of the Jill episode which I have described in Chapter 4. I already recognized the unique value of myself doing the investigations which were a focus of my research in the course of the Dan and Tristen paper towels activity. Within a classroom context a similar opportunity arose when I asked Jill if I could try some manipulations with the convection box. The nature of my conversation with Jill changed as I joined the problem context in a more significant way by attempting to physically participate in the experiencing of phenomena in a way similar to her own way.

I continued this participatory approach during the **Invent a Machine** project when I arrived with an assortment of hand tools, wood, wheels, and hobby motors. Ms. B. introduced me to the class as a resource person. I have described my rationale in more detail in Chapter 4, and the three subsequent chapters portray the quality of my engagement with different groups and individuals. My presence in the classroom introduced additional complexity to the social-cognitive dynamic of the classroom as a whole. For instance, the presence of a second adult with whom the students could interact played a role in the development of thinking for many students. Ms. B.'s perspective on the changed dynamic that my presence introduced will be presented later in this chapter.

The dissemination of ideas and actions

One of Ms. B's favorite teaching techniques was to involve her class in guided discussion. She was very good at this and most students participated enthusiastically by contributing ideas and suggestions. Ms. B. would from time to time invite students who had raised a particularly good point, or who seemed to have a problem, to pursue an independent investigation during class while the remaining students worked on other activities. Ms. B.'s invitation was invariably accepted by students, and they would report back to the rest of the class what they had found. The episode in which Jill spent an entire class investigating the convection box is an example of this type of engagement. In short, Ms. B. is an excellent teacher who has a special talent for encouraging her students to be inquisitive, take action on their curiosity, and report their findings to a larger community. These techniques are an intrinsic part of scientific approaches in general.

The comment which follows is intended more as an observation than a criticism. How can one criticize this kind of teaching? Why should one criticize this sort of approach to engaging students in thinking about science? My comment emerges from my own observations, student comments, and Ms. B's reflections of this teaching/learning technique.

I noticed that an hierarchy of opinion had developed among the students in Ms. B's grade nine class. In short, students considered the opinions of some of their peers to be more important than those of others. Usually when these students spoke, which was often, most of the "lesser lights" would withdraw or simply concur without comment. Ms. B. would try to involve other students and a discussion would develop which involved typical non-participants but it seemed to inevitably end with closing arguments from the "star thinkers". Sometimes, it seemed to me that the "brightest" students would politely defer from commenting on the ideas of the so called "lesser lights". In other words, while the class appeared to be a community of thinkers contributing a large number of ideas available to the whole class, it seems that some students were excluded. Other students seemed to focus more on being heard by the teacher rather than listening to each other during class discussion.

I was not aware of this hierarchy when I joined the class, and I believe that this allowed me to interact with all students more constructively than if I had known. Were the students aware of this complex competitive dynamic or hierarchy of intellectual authority among their peers? The following excerpt from my conversation with Clarence about risk and competition touches on this question:

> **Clarence:** ... As I said before, we would have learned more if it hadn't been so competitive.
>
> **Leo**: How would you have learned more if it wasn't so competitive?
>
> **Clarence:** Ok, if I want a good mark, say I want a 95, then I'm not going to do something totally different from what the book has said already, and then I just follow what the book said. If it wasn't so competitive then I couldn't care

> less what the result is so I'd just try anything. I'd certainly be a lot more open to ideas than I was during this.
>
> **Leo**: So you have said that you would take more risks. Would it change the way that you did the project? Would it change the way that you thought during the project? Do you think your project would have looked a lot different if this project hadn't been so competitive?
>
> **Clarence:** It's still kind of competitive in a way, you are still trying to beat your friends. It's almost like a chain reaction. Let's say that Dan and Tristen came up with a really strange idea, then I'd probably try myself to come up with a really strange idea. So we'd just put those ideas together and test those ideas. They are kind of a society ... sort of a herd or whatever you call it ... they can mock people a lot for what they do in school so they can feel higher than them ... so there is still a certain amount of competitiveness even if it is not formally shown.

Clarence is one of the intellectual leaders in the class. He is naturally inquisitive and I often observed him noticing what other students were doing and being interested in the kinds of results they were obtaining. For instance, Clarence approached Jill as she worked on her impromptu convection box exploration and contributed some of his own ideas in an attempt to explain the observations she was making. However, when I asked her about what Clarence had done she seemed to be disinterested and dismissed what he had done by saying "Oh that was just Clarence's idea." Jill clearly had strong ownership about her own investigation and at that point was not inclined to incorporate Clarence's ideas into her emerging world of significance. Her response did not deter Clarence in the least bit from trying out his idea. In this case, the focus of attention was on the phenomena which each student noticed, and not on their relative intellectual status in the class.

In contrast, the dissemination of ideas in the competitive environment of the Solar House project was something that was done intentionally and consciously by students and was influenced by their perceptions of each other's intellectual standing. After all, their mark depended on the performance of their creation relative to the performance of the projects of the other students. For instance, Tristen spent a good deal of time "visiting" the work spaces of other students and watching what they were doing. I noticed one such occasion on which he suggested to two of the so called "lesser lights"(Ronnie and Willie) his idea that charcoal could be a useful heat absorbing material for their solar house. This was Tristen's own idea which he seemed to consider unworkable in the context of the house that he and Dan were constructing. Perhaps Tristen felt that offering his idea to Ronnie and Willie was one way that he could see it put into action that did not threaten his intellectual standing. He regarded, as did most students, Ronnie and Willie to be unlikely to achieve a grade higher than his and Dan's. Tristen did not, for instance, offer this idea to Clarence whom he also visited. Perhaps it is easier for students to share ideas with those they do not consider to be "serious" competitors. (It turns out that Ronnie and Willie surprised everyone including themselves, Tristen, Ms. B. with the success of their project.)

Ms. B. was not aware of Tristen's contribution to Ronnie and Willie's project. However, she was aware of Tristen's apparent dissatisfaction with the progress being made on his and Dan's project. Ms. B. describes Tristen's involvement as follows:

> **Ms. B.**: I think Dan and Tristen's partnership was an example of ownership. Like I heard Tristen say a few times about this high-tech project that it would never work. And yet he went along with it. I don't think that he ever took ownership of his ability to make a difference. Maybe he doesn't have much ability with Dan to make a difference but I don't think he ever took ownership of it in the same way that Dan did.

Although Clarence described the "charcoal idea" as being "owned" by Ronnie and Willie, it is noteworthy that he chose to incorporate the idea into his own design after noticing it in one of his visits to their workspace. Clarence clearly considered the "black oil" idea to be his own unique contribution. It seems that collaborative sharing of ideas occurs mostly after a student has taken ownership of a building project by making a contribution which they consider to be original among their peers. It may be that by shaping her/his problem environment a student effectively opens it up for more collaborative interactions with other students. Ms. B. speaks to the issue of ownership in the following:

> **Ms. B.**: ... One thing I noticed was that if a kid had a chance to see their idea through, to being implemented, they really stayed involved and if they didn't, if it had to be abandoned, they kind of gave up interest. ... I think most kids benefited from seeing and hearing their classmates results. Not necessarily from copying, because they probably just by osmosis picked up lots of ideas.

Students may be more willing to share ideas with others when they do not consider them to be competitors. For example, it may be the case that Tristen considered Ronnie and Willie to be essentially working on a different project in the sense that he considered their goals to be different from his own. Ronnie and Willie simply wanted to find a way to work productively and get the job done while Tristen wanted to obtain a high grade.

I also noticed the intentional non-dissemination of ideas during the Solar House project. For instance, the rivalry between Sean, another intellectual leader, and Dan intensified during the Ice Cube activity. At the end of a building session in the IA Tech workspace Sean explained to me that he did not think that Dan's "vacuum idea" would work.

However, he added that he did not intend to share his observation with Dan until after the project was finished because he was competing with Dan.

The atmosphere of competition which permeated the Solar House project was not present in the Invent a Machine project. The classroom atmosphere which emerged during this project was different in the sense that students were more interested in each others' ideas and actions. For instance, on various occasions the two girls who built the Dog Washing machine were invited by nearly all the students in their class (and even some from outside the class) to give impromptu demonstrations of their machine, which they did with obvious enjoyment. The various workspaces of the students in this project seemed to be more open in the sense that students would often approach another group's workspace in order to experience the machine by manipulating its components and seeing how it worked. The designers of the machines did not seem to mind and often stood back and watched with pride as other students explored their ideas. For instance, during a class early in the project the Cactus Watering machine was briefly visited and "put in motion" by every student in the class. As the project progressed, students began to spontaneously help each other (e.g. holding and balancing materials) when they noticed another student in need of assistance. Students seemed to engage in these kinds of participatory engagement after visiting and noticing aspects of other students' work. In other words a sort of recursive feedback seemed to become established. As students visited and experienced other projects, their world of significance and the possibilities for action expanded. As their world of significance grew larger, the opportunities to act in a more complex way with other students as co-participants also increased.

How did the two projects differ? Viewed from a broad perspective, two aspects of difference are present: the nature of the creative control and the criteria for success. One difference resides in the degree of creative control that students were able to assume over the development of their tasks. In the Invent a Machine project the nature of their tasks continued to be shaped as the students built their machines. Students took the responsibility for establishing the criteria by which the success of their invention would be determined. Part of the assignment was to create and bring forth their own task.

In contrast, the Solar House project invited students to create and compare their **versions** of what was essentially the same task in the sense that the criteria for their success were externally established. The criteria for their success were scientific in nature in the sense that they were based on measurements taken under controlled conditions which emerged out of the curricular unit they were studying. There was really no opportunity for students to establish their own criteria or modify the existing criteria. In this sense students' involvement in the Solar House project could be described as less embodied than it was in the Invent a Machine project. This does not mean that there was no opportunity for creative thinking. As noted earlier, students in the Solar House project did engage in creative thought involving the use of materials to accomplish the task. Many students, in describing the pleasure they experienced in putting their ideas into action and seeing them work, seemed to develop a more complex notion for their own understanding of the criteria for success. Some students even began to question the nature of the shape of the problem and inquired with Ms. B. about the design of her assessment strategy. However, the emergence of significance for these kinds of understandings seemed to occur **after** the project was completed as students reflected on their thinking and the relative success of their machine in relation to the external criteria. Perhaps, for most of the students in the Solar House project, a recursive quality to their experiences in designing and building and developing an understanding for the shape of the problem had not emerged by the end of the sequence of their work. This suggests that the emergence of recursion as a component that a student considers useful in her approach to action-thought may depend on how she views herself to be involved in shaping the "end of the problem". Perhaps a student will be more capable of recursively "visiting" multiple endpoints where they consider themselves to be re-entering a process of beginning the problem again when she is fully implicated in shaping the nature of the end of a process of action-thought. If so, then the pedagogic approach of facilitating effective student action by primarily **acting for** students (e.g. by not fully involving students in the determination of the boundaries and constraints of a problem or by setting constraints on how groups are constituted) may have unintended consequences. Perhaps the pedagogic approach to facilitating viable action-thought would be improved by reconsidering it as a process of **acting with** students in that it may enhance the likelihood that students will see connections between the processes of action-thought and its products.

The students in the Invent a Machine project engaged in action-thought on a broader level in the sense that they seemed more aware of the shape of their ways of acting-thinking as the project developed. By actively participating in shaping the problem each student laid down her/his own path in walking. One could describe this as a process involving a sequence of continual recursive engagements throughout the course of their work. It seems that a qualitatively different environment for action-thought emerges out of a community of builders who are able to interact and collaborate on a continuous and repeated basis.

Recursive visiting is an experiential process for developing understanding from which new possibilities and a new environment for action-thought emerge.

Entering into effective action

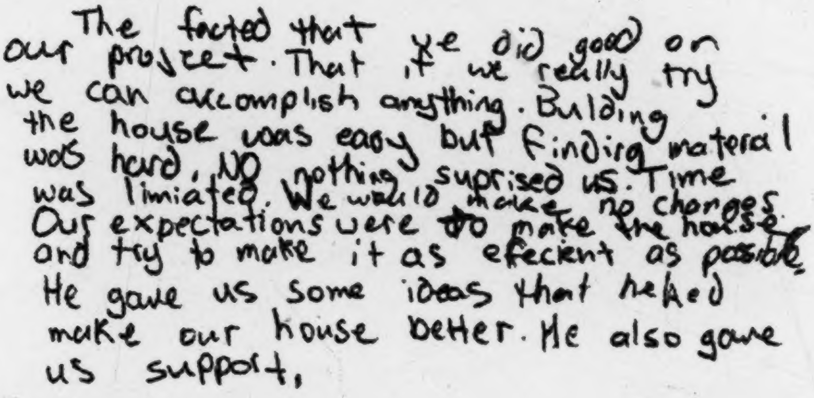
Ms. B encouraged the students to make a sketch of their initial plan. They were required to show the diagram to her before proceeding with their construction activities. A majority of students were able to accommodate this request with plans showing varying degrees of detail, and quickly entered into construction activity. However, some students, like the aforementioned Ronnie and Willie, seemed unable to begin in this way. They had not been successful in some of the lead-up activities to the Solar House project, and tended to fool around instead of attending to the task at hand. On several occasions Ms. B tried to help them in their planning with little success. I became interested in Ronnie and Willie and sat down with them. The excerpt which follows is my interpretive account of what happened .

Ronnie and Willie's Solar House

> As usual, Ronnie and Willie are having trouble getting started on their project. They appear glum as they sit and watch other students who have already begun. "She (teacher) won't let us start until we draw a plan ... that's stupid" Willie complains to me. Ms. B. overhears the comment and asks the boys what they need. Ronnie says that they need to try out the materials in order to get some ideas. Ms. B. agrees and Willie and Ronnie begin handling the styrofoam, the insulation and the other materials that are available. They quickly assemble a box as a prototype for their idea. Both boys are suddenly very focused on their work.
>
> New ideas emerge from manipulating the materials and new manipulative actions emerge from each idea. "How big should we make the window Willie?" " I don't know, let's just try using this glass." They try holding a small rectangular piece of glass Ms. B. has given them against one side of their styrofoam box. "That's too small, we need to get as much heat in as possible" declares Willie. Eventually Ronnie and Willie choose a pane of glass that fills one whole side of their solar house. "How are we going to keep the heat in?" asks Willie. "I know what we can do, let's make a cover ... we can put it on after." They spend a long time (nearly a whole class) working on the design of a cover for their window. After trying materials like tin foil and pink insulation they eventually construct a hinged styrofoam shutter with a metal foil covering facing inside. They explain to me that they think this design will keep heat from radiating or conducting away once the shutter is in place. They proudly demonstrate their innovation by opening and closing their shutter for everyone who stops to see what they are doing.
>
> Tristen notices that Ronnie and Willie are working productively. This is something new (normally they just waste time) and he is curious to know more about what they are doing. The two boys happily demonstrate their idea for Tristen. "How are you going to keep the heat in?" Tristen inquires. Ronnie points to the shutter and closes it again. "You should try putting

> charcoal inside, it will help to hold the heat." Willie and Ronnie seem pleased that Tristen is willing to suggest an improvement to their design and a couple of days later they incorporate the idea into their solar house design.
>
> The relationship between the two boys and Ms. B. changes significantly during the project. The boys are eager to explain every new innovation during her visits to their work table. Ms. B. seems to visit their work area more often and stay longer during each visit. The boys talk constantly to each other about their progress. "Hey, we're actually working ... I can't believe we're actually working" Ronnie happily announces. "Come on Willie, hurry up ... get the tape."

The explore-plan-act triad seems to be a complex and recursive dialectic with varying entry points for different persons and tasks. Ronnie and Willie did not seem to be able to imagine an end-in-view in the abstract. Hands-on manipulation was needed to start their flow of ideas. Ms. B's flexible approach to student knowledge-building enabled her to allow them to depart from the conventional requirement to construct a written plan first, thus enabling them to get started. Ronnie and Willie worked with what was for them an extraordinary degree of diligence and created a very successful solar house (see Figure 35). In this process their relationship with Ms. B was transformed into conversations about their ideas rather than about their behavior. Their conversations with Ms. B. became more frequent and extended, changing the learning/teaching relationship. Willie's and Ronnie's written response to the reflection worksheet is presented in Figure 34.



The facted that we did good on
our projcet. That if we really try
we can accomplish anything. Bulding
the house was easy but finding materal
was hard, NO nothing suprised us. Time
was limiated. We would make no changes.
Our expectations were ~~to~~ make the house
and try to make it as efecient as possible.
He gave us some ideas that helped
make our house better. He also gave
us support,

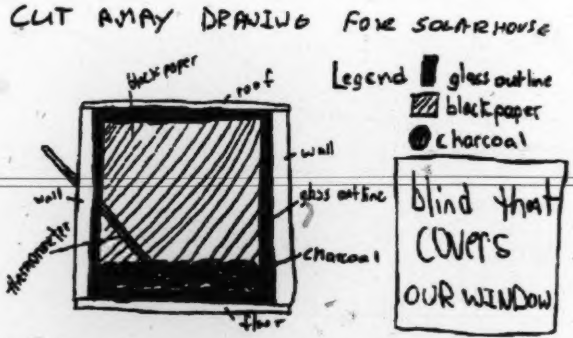
Figure 34: Willie's and Ronnie's response to the reflection worksheet

Ms. B.'s engagements with Willie and Ronnie must have had some significance for her. Two years later, she vividly recalls the transformation:

Ms. B.: There were many kids though who weren't successful on paper and pencil tasks who became successful ... in the construction, kids who had taken no initiative in the traditional approaches who took lots of initiative ... and created something from the Machine or from the Solar House, I think about Willie and Ronnie ...

Leo: Would Keith be an example as well?

Ms. B.: Yes. Yes.


CUT AWAY DRAWING FOR SOLARHOUSE
Legend
glass outline
black paper
charcoal
black paper
roof
wall
wall
glass outline
thermometer
charcoal
floor
blind that covers OUR WINDOW

1. a) Our house gained maxium energy through the window.
b) We had black paper on the walls and charcoal on the floor, our roof had tin foal on it.
c) The coal and the black paper held the heat in. We also used a blind to cover the window so that minium heat was lost.

Figure 35: Willie's and Ronnie's depiction of their solar house

There were many instances in both the Solar House and the Invent a Machine projects where students who were having difficulty participating successfully in the regular activities of the science curriculum found ways to enter into effective action-thought. This occurred when they were given the opportunity to think by developing their own building environment. Typically students are not expected to create or even think about the process by which they can put their ideas into action. Self-directed building is a kind of engagement which requires a student to be continuously aware of the path she is laying down. Focusing on improvising small solutions on an ever changing pathway seems to reduce the anxiety of reaching a final destination. Once again, allowing students to participate in determining the nature of the outcome to a process of action-thought seems to provide adequate opportunities for them to engage in viable thinking (i.e. thinking that holds significance for students) .

Understanding is embodied. Many students are not able to verbalize their understanding adequately but, given the opportunity they are able to act it out in a complex and creative way. Our schools place a high value on verbalized and symbolic knowledge. Perhaps such projects as the ones described here can help to expand the notions of what it means to know into a more diverse set of capabilities. For some students (i.e. Paul, Ronnie and Willie) the experience of encountering success opens the door to more academic success.

The question of how the emergence of success for specific students in either the Solar House or Invent a Machine projects influenced their future academic success is not one that I have attempted to address in this study. However, I did encounter students from the two projects with Ms. B. in other contexts. For instance, in the following academic year I encountered many students from the Solar House project in the corridors of the school where the Mousetrap car project was being conducted. Invariably they would greet me enthusiastically and tell me about how much they had enjoyed the Solar House project. One of the students with whom I briefly met a couple of times in this way was Willie. These discussions revealed that he did not consider the Solar House project to have contributed in any significant long term way (positive or negative) to his current academic pursuits. Willie explained that the Solar House project was interesting and fun to do, but that it was only significant for him during the time he was involved in it. I also met students from the Invent a Machine project at a city wide science fair a few months later. Two of these students, Tony and Sarah, described their experience in the Invent a machine project as being helpful for them in conducting their science fair projects. Sarah explained that the thing she found most helpful was the experience of seeing a more extended project slowly take shape during the Invent a Machine project. Perhaps developing an holistic understanding of the shape of such an open project helped enhance her confidence in her ability to be successful in her upcoming science fair project. When I asked Tony if the Invent a Machine project had helped him develop his science fair project he gave me a big smile and said "Oh yes!". He explained that the experience of building with various materials helped him to think about how he would construct the experimental device he used to conduct his science fair project.

The impact that self-directed building engagements in science. have on future academic success remains an open question. I can say that all of the students I talked with subsequent to their building activity considered it to be a worthwhile experience. The fact that they were able to remember what they had done and talk about it with me in detail is itself important. Perhaps the most important outcome of this kind of engagement in science has less to do with the specific science concepts that are involved; rather it allows one to experience a process of building personal significance for a way of engaging in a science learning context.

One of the outcomes of the Solar House and Invent a Machine building projects, that was unexpected for the students and for me was the way that the established classroom hierarchies seemed to become less salient. Many students were surprised when they discovered that the students they expected to be most successful were not. Students accustomed to a high degree of success compared to their peers also found such outcomes surprising. One outcome of this challenge to the normal hierarchy of success was that some students began to take notice of work done by other students whom they would not have considered before.

A world of significance emerges for the teacher

At the end of the Solar House project, my supervisor and I interviewed Ms. B.. An extended excerpt from this interview is presented in Appendix C. Ms. B. is referred to as Bridget in that interview and in the subsequent segments included in this chapter. The purpose of our interview was to get a clearer sense of Bridget's impressions of the issues which had emerged as important for her during the project. A secondary goal of this interview was to refine our research approach and develop implications for classroom science teaching. My supervisor and I conducted a second interview with Bridget two years later. The purpose of this interview was to get a sense of how Bridget was thinking about and using extended building projects in her science classrooms after our research engagements had concluded. Selected portions of the second interview are presented in this chapter.

The choice of Bridget's science classroom as a suitable research setting was based on two criteria. First, Dan and Tristen, who had participated in the Paper Towels engagement were members of one of the grade nine science classrooms taught by Bridget. Their presence allowed me to continue my research engagement with them. Second, Bridget and my supervisor had worked together in an earlier research project. That research engagement involved three of the four main qualities (i.e. open-ended, physical building, extended time, self-directed) that we wanted to include in the Solar House project. Only physical building was new. In other words, my supervisor was confident that Bridget would be receptive to our ideas.

We wanted to directly involve Bridget in the determination of the specific details of the nature of our involvement with her students. After listening to us describe in general terms the qualities of the learning environment in which we hoped to involve her students, Bridget selected the beginning of the unit on Heat and Energy as the best point for us to enter the classroom on a continuous basis. We kept our descriptions of the desired student engagements relatively vague in order to allow her to structure them in a way that she felt would suit her students and herself. The following segment from our interview illustrates Bridget's thinking at the beginning of the project:

> **Heidi**: ... What were your impressions when we first came and we said we want to study how students function in self-directed environments?
>
> **Bridget**: I realized two things, I guess. First of all that I couldn't follow up just on your ideas ...I also realized that I had some control over it because I think at the first I saw it in terms of either/or ... I mean ... either we did what you wanted or we did kind of what I thought the kids needed to do ... So that was my first impression ... just all kinds of questions; "How long it would take?" and "How far out of the curriculum would we have to go in order for you to meet your goals?" ... I couldn't see any way of you meeting your goal of wanting the open-ended investigation and my meeting my goal of having something the kids could succeed at.
>
> **Heidi**: So how did you come to this decision that a potentially do-able thing was to design a one-room house, because this seemed to come up quite suddenly?
>
> **Bridget**: ... I phoned the consultant for Edmonton Public ... and spoke with him and he said "well why don't you just do a one-room house" and then "lo-and-behold" I looked in the textbook and that's what they had. ... So that was helpful. He gave me some ideas and then I saw some things falling into place. I saw the "ice-cube keeper" leading to ... well, leading the kids to make some conclusions that would be applicable to the solar house.

Classroom research is a significant perturbation for a teacher and her/his students. It is difficult, if not impossible, to determine the impact a research engagement on learning or teaching for the members of a classroom environment before it begins. However, it is important to try. The reason for this is obvious. A researcher has an ethical and professional responsibility to try to ensure that their engagements with students and teachers will not negatively impact on his/her learning/teaching.

The ways in which these concerns are addressed are multidimensional and multilayered. A classroom research project is scrutinized by a university ethics committee, the school system, the principal, and the teacher. Each of these stakeholders has a legitimate role to play in the process of bringing a viable project of research into a classroom environment. However, once a research project is approved, a researcher interacts with the teacher on a day to day basis. How the classroom teacher is involved in a research project which places its focus on the nature of students' thinking can have a significant impact on the nature and the quality of the engagements a researcher has with students. How should the classroom teacher be involved in such classroom research engagements?

Bridget saw a need to balance multiple goals as she began searching to find a way to put the Solar House project into action. It seems that she did not consider the research goals of the project to be tightly connected to her own teaching goals in the classroom. However, once Bridget took our rather vague idea (as she saw it) and began to shape it into something that she thought could work, a new significance began to emerge for her.

> **Heidi**: You indicated that your teaching unfolds, so to speak. When you saw these possibilities and as they unfolded, were there any areas of surprise or unexpectedness or where you saw things going in a certain direction and you felt you had to change your tact or direct things in perhaps a different way from what you had predicted?
>
> **Bridget**: ... after [the consultant] talked about the one-room solar house I was surprised to see that the very same thing was in the textbook. But ... it was in the textbook in a way that hadn't seemed very ... promising either. So I don't know if it was as much an area of surprise as seeing the potential for us to go with that activity and that it could likely be successful ...
>
> **Heidi**: When you first introduced the house you had already gone and purchased some fiberglass. Can you tell us a little bit about that?
>
> **Bridget**: I think that came out of my conversation with [the consultant]. He suggested that I keep it simple, to a one-room house, and we talked about some of the materials that I might use and some of those were the same from the ice-cube saver ... You know, the cotton batting and the sawdust and those kinds of things and he suggested the purchase of polystyrene. ... It was ... not serendipity exactly, but all kinds of things came together, it seemed, in the last few days before I introduced that activity to the class. ... Then seeing it in the textbook ... gave it a kind of legitimacy too. So I was pretty sure it was in the curriculum and the fact that it linked back to the ice-cube saver which I had done before in my class. So I knew something about the materials that would be useful for that and I know in my own learning style, I learn best from doing something but once I've done it there's all kinds of little hooks in my mind that I can hang new experiences on. So I could see how I could use the experience of doing the ice-cube saver, when I did it years ago, to do new things with my class this year.

Once Bridget was satisfied that the solar house project was a legitimate part of the curriculum she began to search for ways to make it work. Her conversations with the consultant and her ongoing conversations with us helped her envisage new possibilities for action with the solar house project. Bridget had entered into a process of action-thought in which a new world of significance was beginning to emerge for her. The goals of the research project and the teaching project began to overlap. Bridget was exploring a new territory of action-thought, we were active learners, and so were her students.

I want to draw a distinction with research approaches which focus on student learning where students are engaged in activities which are designed and, usually, implemented by someone other than the teacher. I think there are advantages to including the teacher in the design and implementation of the research activities in which her/his students will be engaged. Bridget's way of participating in her classroom changed as the project evolved. Once a high-activity classroom is set in motion and many people are acting in parallel it places special demands on a teacher. One often finds oneself dealing with the needs of several people at once. However, a high-activity classroom also opens up possibilities for a teacher to have a kind of conversation with individual students that is not present when addressing the whole class. Bridget seems to have noticed the qualitative differences in the nature of the conversations that she was able to have with her students. For instance, Bridget describes how she noticed some of the qualities of my style of engaging students as they were working:

> **Leo**: ... Were you acting in your standard teacher mode as you were interacting with those kids during this self-directed project? Was there anything different about the kinds of interactions that you had with kids while the project was developing?
>
> **Bridget**: ... you asked about "was I acting in a standard teacher mode?" I don't think so ... I think I ought to tell you that I really saw my interactions, my teaching of this group, the grade nines and the grade eights ... as a kind of a chance to make my mark ... so my ego really got involved there and I saw the possibility of having, of them having a new and better experience by me structuring all kinds of activities for them.
>
> **Bridget**: But I think with all my classes ... the way it operated ... was to immerse them in activities and that was a new experience for them and not always helpful to them. Sometimes they needed more structure than they got, so I wasn't operating in my standard ... well I was and I wasn't ... I wasn't operating in my standard teacher mode because things were much more open ended with this project on the solar house than I would ever have structured them on my own. It would have been much more aiming for closure. You know, "Ok what have you learned from this" and their discussion soliciting the key ideas that I wanted them to learn, and so it was quite a challenge for

> me and I learned a lot from watching you Leo as you maintained your neutrality.
>
> **Bridget**: I mean reading about some of the reflection questions that the kids wrote when they responded to whether it was helpful or not to have you in the classroom. I remember Dan and Tristen writing that they just scrutinized your face for clues that you ... that they were on the right track and I realized as I read that that kids do that. I mean we all do that. ... Well anyway (laughs). I mean it's hard to be neutral. It's so hard to be neutral and not encourage by your ... you know, your facial ... I learned a lot from watching you Leo about how to be encouraging or open without leading them down certain paths and I think it's inevitable in a way that we do that just because of our unconscious responses to what they are saying.

Teaching as learning is a powerful metaphor which is central to an enactivist perspective. All good science teachers have an intrinsic curiosity for the phenomena, activities, and concepts which they ask their students to explore. This was certainly true of Bridget's orientation, especially in the whole class discussions I observed her conduct with her students before the Solar House building activity began. Our presence, myself and Heidi, in her classroom became an occasion for Bridget to learn through her interactions with us and through the new kinds of interactions she was able to have with her students.

Bridget describes one aspect of my style for engaging students as "neutral". However, I would not describe my style in this way. I certainly was not neutral during my engagement with Ronnie and Willie (e.g. I made suggestions and offered my opinion as to what I thought would and would not work well). I think it is more accurate to describe my approach during the conversations I had with students as being one that focuses on listening for and contributing possibilities for action-thought. Curiosity or wonder is a way of being that is easily noticed by the participants in a conversation when the ideas which emerge are brought into the open. For instance, students in the Solar House, Invent a Machine, and Mousetrap Car projects would actively listen (i.e. look for facial expressions and body language) as I listened to them describe ideas. When an idea occurred to me during a conversation with a student I would usually say so and describe what I was thinking. I consider this to be an important element of an enactivist approach to listening which separates it from a constructivist approach. A constructivist listens and takes in information about the persons way of acting and the setting, an enactivist listens and brings forth action-ideas which contribute to shaping the setting and the persons ways of engaging the setting. In addition, listening involves more than an interaction between persons and a simple comprehension of language. Productive listening has a physical-phenomenological dimension that involves interactions between persons acting together to experience phenomena in a setting. I will describe this in more detail in the following section.

An emerging style of teacher-student discourse

Bridget describes a conversation that emerged as being significant for her as follows:

> **Bridget**: I think there were a couple of points that helped me realize the value of being neutral or less directive. One of the points or one of the conversations that I'll talk about is Helen, Karla and Laura who were planning to build their solar house with copper wire wrapped around those tubes ... and I listened to their whole explanation and asked questions and at no time did I discourage them from doing that and that seemed kind of like a turning point for me in my interactions with the kids because I realized ... I mean I would not have encouraged that if my goal had been that they get good results. I wouldn't have encouraged them to pursue that line. I asked them about some other things they could have done but I never said "well I think that's a stupid idea". As it happens, through some interaction either with you or clues I gave them or among themselves they decided not to do that. They went instead to more solar collectors with black paper wrapped around the tubes.
>
> **Leo**: Did that change the way that they eventually spoke to you and had conversations with you? Were there any new ideas that may have come from those kids as a result of that kind of interaction with you?
>
> **Bridget**: Yes. I've got so many ideas here. I don't know if I can get them all out ... Like watching you and listening to the way that you interacted with the kids really helped me change the way that I interacted with them. So I want to make sure that I make that point. I did change from being more directive to being more open-ended ... and in questioning just to what the process was ... I mean being less content and more process...

As the project continued, Bridget became interested in learning more about some of the ideas that my supervisor and I were thinking about at that time. We shared a paper with her that we were about to present at a research conference. In one section of that paper, I describe Dan and Tristen's and my own explorations with the Paper Towels activity (see Chapter 6).

A world of expanding significance was emerging for Bridget as she engaged her students in this kind of conversation. As she began to notice the kinds of possibilities that her students could construct, she began to modify her teaching. In her own words:

> **Bridget**: ... a couple of things that I realized along the way ... like I read your paper that you delivered ... the paper that you wrote about Dan's enthusiasm for watching how the paper towel soaked up water and your own interest in the pattern, the shape that the absorption took, and I realized from your looking in detail at that, that the ideas that I got enthusiastic about around the

> solar house and tried to encourage other kids to follow up usually fell flat. I don't think ... I didn't have the benefit then of reading what you'd written about Dan and your own ... but I think I realized at some point that my pushing my enthusiasms wasn't leading them to do anything and **at that point I just listened, I spent more time listening and just letting them take the lead** instead of me trying to ... kind of "running down a path ahead of them" and saying "come this way, come this way."

She began to actively listen, to allow potentialities to emerge as students described their activities in the building environments they created. In addition to this, Bridget began to think about how she could encourage the growth and emergence of new possibilities that arose in a more self-directed fashion.

Teaching as listening (Davis, 1993) is a powerful metaphor for teaching. It helps to orient the teacher in such a way that participating in a common project with her/his students becomes possible. I want to be careful not to misportray Bridget's teaching. She is a very capable and confident teacher with a strong constructivist orientation. Participating in a new way in a classroom environment which was created as much by her students as it was by her and by our presence allowed some new understandings of the teaching and learning process to be brought forth.

Perhaps the most significant thing about learning/teaching in an enactive classroom is the way it allows the students and teacher to think about the process of engaging in scientific action-thought. Bringing personal ideas into a public forum is an important and essential component of science and science learning. Personal ideas become enabled in a powerful way when they are enacted in a social context. Finding ways to encourage all students to bring forth their personal ideas into a domain where they can develop complexity is a central problem of current research in science education. An action-oriented environment for learning/teaching science enables student thinking through action-thought and helps to encourage the emergence and development of new pathways of action-thought by every student in the science classroom. In other words, students who are normally hesitant to allow their ideas to emerge and take shape in the classroom social domain are able to contribute when they participate in action-oriented building/learning environments.

Bridget was not the only person in the classroom who was actively "listening". Students, especially in the Invent a Machine project, also listened to each other. The way in which "listening" occurred is a more complex process than one based only on language. The point I wish to make here is that students can "feel" the enactive learning environment in which they participate and a "felt significance" emerges for students which recursively "feeds back" to nurture and sustain the development of their thinking. Evidence to support this claim is based on my own experiences as I participated with students in the research projects. I noticed a dramatic increase in the social classroom energy level, as compared to the prior classroom activities I observed, during the Solar House and Invent a Machine projects as students "got into" their work and Bridget noticed that students who were normally slow to become involved in tasks were enabled to take ownership of the development of their own thinking and understanding.

My approach to productive listening emerges out of my interest in natural phenomena and the way students think about and engage the phenomena they bring forth. For instance, in the Solar House project I found that I could have more complex conversations with students when I began to physically interact with the phenomena and materials that were a part of a student's workspace. In the Invent a Machine project I became even more deeply involved with students' action-thought. This was partly enabled by Bridget's decision to introduce me to her students as a resource person with expertise they could use if they wanted to do so. I found that nearly every student wanted to include me in their project in some way. My engagements with each student and their workspace was different but there were some commonalties. For instance, I would focus my attention on the setting and the natural phenomena emerging from the setting. In this way, my agenda for engaging became similar to the student's. We both focused our attention on solving a common problem. The advantage of this is that my engagement with a student became an opportunity for he/she to **enact** rather than **react** their understanding. Rather than ask them specific questions about what or how they were thinking I would participate in the action-setting as a productive helper. In this way I was able to listen to students as they described what they were trying to accomplish as they worked, either in spoken language or silently in manipulative action. In a sense, my research focus was not aimed toward revealing anything, it was to listen for a way to contribute to the development of more thinking. I was listening for more than what had already passed, I was listening for the moment and looking toward the future. This orientation allowed me to develop an understanding for segments of many separate trajectories of action-thought. Students considered me to be acting not only for their own benefit but also for the benefit of the entire class. In this way I was able to maintain a connection to individual projects while engaging the whole class. Productive listening is not so much a technique for hearing as it is a way of being in the world.

Bridget's perspective on the development of students' thinking

Earlier in this chapter I presented a description of how Ronnie and Willie entered into a productive building process during the Solar House project . Bridget considered this to be a significant accomplishment, both for her and the two boys. She comments as follows:

> **Bridget**: I can't remember what Willie and Ronnie had discovered but it was it was really incredible work for them. I mean it would have been excellent work for any group but they had discovered something and I remember bringing some other kids over there and saying something to Willie like "Let me pick your brain" ... I think it was Laura ... and they taught Laura, or told Laura, the line of inquiry they were doing and that for me marked a turning point in how they ... in the responsibility they took for their project. It seemed like after that ... and also after you had them in your room and gave them some special encouragement that they took some ownership and got a really good house built. So part of what I learned, part of the new ideas that I picked up, part of the process I learned was to let them lead with their ideas and lots of new ideas emerged.

There are a number of interwoven ideas which emerge from Bridget's comment above. It is evident that she considered them to be students who were not often successful in their science activities. Inviting the two boys to present their ideas to Laura, who was often successful in science activities, seems to have been a way for Bridget to encourage Ronnie and Willie to sustain the " intellectual breakthrough" they achieved.

My early interaction with the two boys seems to have helped them "break inertia" and enter into a more proscriptive form of thinking in the sense that they began to imagine possibilities rather than "see" constraints for the development of their thinking. A proscriptive approach is a good description of how I tried to orient my thinking as I sat down with them to try to encourage them to "break free" from the unhappy and unproductive state they found themselves in at the beginning of the Solar House project. In other words my interest during my conversation with Willie and Ronnie focused on phenomena and the way we could engage the phenomena associated with their task rather than on the behavior of the two boys themselves. When they explained that they thought that they needed to begin by working with materials and Bridget agreed, I simply replied "Ok, let's do that." My presence may have helped to enable the transition to action and I remained with Ronnie and Willie as they quickly began cutting and arranging materials for a preliminary solar house.

The transition to action also allowed me to "productively listen" with the boys as they worked. "Listening productively" involves participating in the noticing of phenomena and contributing to the development of solutions as the problem emerged and took shape. In other words, by focusing my engagement on working on the same problem as Willie and Ronnie I was able to get a sense for the way they engaged their environment (which included me) to bring forth a world of significance. I was not so much concerned with the conceptual correctness of any of their ideas (spoken or demonstrated) as I was in encouraging the boys to pursue ideas as they emerged. For instance, at one point Ronnie and I held either side of the open end of the partially completed styrofoam box (solar house) as Willie manipulated the light source to see where the shadows "fell" inside. As we did this, the idea of an angled window occurred to me and I suggested it to the boys.

Was the angled window idea my idea alone? No. The idea emerged out of and existed within the interaction between the three of us working together. Did Ronnie and Willie adopt the angled window idea? That is not really important. The purpose of "productively listening" with students is not to encourage them to develop or adopt any particular idea, it is to allow students and me to pursue interacting trajectories of action-thought. Some of the ideas that were first spoken by me were adopted and some were not. Perhaps the angled the window idea was transformed into a new idea. In the end Ronnie and Willie chose not to include an angled window but they did "prop up" the side of their solar house with a window in order to maximize the illuminated area inside.

In her comment above, Bridget describes me as giving Ronnie and Willie "special encouragement" in a separate room. The special encouragement she refers to emerged out of a technique I tried for a brief time during the Solar House project. At the beginning of the class following the one in which Ronnie and Willie began to make progress I invited them to view themselves on videotape on a video playback unit I set up in a store-room connected to the classroom. The video depicted the boys as they made the transition to effective action in during their previous class and I was hoping that the boys could enhance my understanding of how they were thinking by selecting and commenting on sections from the excerpt I played for them.

The outcome of the video replay engagement with Ronnie and Willie was not what I expected. The boys were very interested to see themselves in action but were unable to describe much about the way they were thinking. I discovered that the video replay was really a new experience for Ronnie and Willie, not a re-experience. Ultimately I abandoned this technique not because of what I had learned after trying it out with Ronnie and Willie but simply because I found it impossible to be in two places at the same time. Using this technique would require me to sacrifice time for classroom interactions with students as they worked. However, it seems that the brief video replay engagement with Ronnie and Willie did have an impact on the social dynamic of the classroom. First, it helped to elevate Ronnie and Willie's cognitive status among their peers, something that was not very high before the project began. Second, it helped to reinforce the notion with Bridget and her students that I was interested in interacting with everyone, not just the "stars" of the classroom.

It is clear that the solar house engagements were a turning point for Willie and Ronnie. They discovered that they could successfully participate in the classroom community . The significance of the project grew continuously for them as they included new ideas in their house. The emergence of Ronnie and Willie's viability in the solar house project increased the significance of the building engagement for Bridget. Bridget's relationship with Ronnie and Willie was somewhat strained prior to the solar house project. It seemed that whenever Bridget visited the boys to check on their work they inevitably needed to be admonished for "fooling around" and pushed to "get on task". As the boys developed momentum in building their solar house, I noticed that the nature of her interaction with them changed. She began to engage in more extended conversations with Ronnie and Willie, sometimes even sitting down at their table and listening as they described their ideas. I am not sure if her invitation to the boys to explain their thinking to Laura was intended as a reward or not but it is clear that the two boys considered themselves to have increased their intellectual stature among their peers during the project.

Becoming an effective participant

Other pedagogic ideas that began to grow in significance for Bridget as she listened to the ideas her students developed during the Solar House project. Two students who stimulated her to think about learning/teaching were Bernie and Paul.

> **Bridget**: Like I'm thinking about when Paul and Bernie developed this special blind that they had on their window that they made out of an Edmonton Transit Pass case (actually it was a sports card case) and they covered one side of a piece of cardboard with foil. He was so proud of that idea, you know. That was their own idea. ... Well, none of those ideas came from me. I couldn't have thought of all the ideas that came. It was the kids. They kind of possessed their idea, you know, and really got attached to them and wanted to

> follow through with how it would work out. I wouldn't think that kind of possession, ownership, involvement with an idea ever would have happened if it had been my idea. **It's because it was their idea.**

Bridget's comment illustrates an essential component of an enactivist classroom. Bernie and Paul's innovation was rather modest compared to most of the others but for them it was a discovery they were now putting into action. Incorporating a sports card cover window into their solar house was a way of getting inside their construction. What changes, if any, did Bridget notice in Bernie and Paul as a consequence of their experiences in the Solar House project? The conversation continues:

> **Leo**: Lets talk about Bernie and Paul a little bit. Would you say that they were acting in a typical fashion?
>
> **Bridget**: No. They changed so much during the solar house. Bernie had been quite ... I have to think of the right words ... typically Bernie's way of being in class would be to fool around most of the class, I mean before this project started, to fool around most of the class and then either to ask special permission to hand something in late and still get full marks for it or do it at the very end. But he never really got hooked on anything ... he never really was enthusiastic about anything in science until we did the ice cube saver and they got really good results.
>
> **Bridget**: They tried cooling it. They did two of them. The first time they did it they had it sitting in the alcohol I think and the second time they put it sitting on some cotton batting and they came in first or second ... and that was like Wow! ... they had quite a low-tech solution and Dan's bombed ... and I think there was something in there that kind of activated Bernie.
>
> **Leo**: That he was on to something and that he had ideas that were worthwhile?
>
> **Bridget**: I think so. Well, remember ... I don't know if you were in class that time but I was collecting hypotheses to explain some concept and Bernie put forth a hypothesis and then Dan put forth a hypothesis and Jill put forth a hypothesis and we looked at all of the evidence for and against and the only one that was supported by all the evidence was Bernie's. And that happened right about the same time as his success with the ice cube saver and I think kind of a light went on, like that's what the mental picture I have is. I think kind of a light went on and Bernie went "Hmm, you know maybe I can do this after all and beat Dan." Anyway he did really excellent work, he and Paul, on the Solar House. Up to that time, they had really done just enough to keep me off their case. And it was at the beginning of term three which was in March that Bernie set his goal to get honors with distinction this term, which he did. That means honors in all of his subjects. So it seems like several things happened around the same time and he really changed in his way of being involved in the class. **He became more of a participant instead of an observer.**

An enactive classroom has an atmosphere of involvement. Bernie and Paul found a way to more fully enact their capabilities for action-thought in the Solar House project. Bernie and Paul focused on satisfying their own local goal for a window that would be "good enough". They discovered that what is "good enough" on a personal level can be equally viable on a broader social level. Enacting understanding in action-thought provides students opportunities to show themselves and their peers that they can be successful. In Bernie and Paul's case it seems that the emergence of effective action-thought allowed them to change their way of being in the science classroom.

Some students had already established effective ways of participating in the science classroom. For them, the Solar House project became an opportunity to re-experience and re-enact their potential to engage in creative action-thought. For example, Bridget describes Clarence's way of being in the classroom during the project as follows:

> **Bridget**: I didn't see as much change in Clarence. Like Clarence took the initiative from the very beginning of the year. He worked with Sean and did that re-enactment of the Hindenburg [classroom demonstration for a school open house]. ... You know, throughout the year they have been putting forward new ideas. "Can we change this?" and "Can we go down this little side road?". And so that didn't change much. He went down his own side road of the charcoal. What was different I guess was that he worked by himself instead of the partners that he's used to having. He got the best results in all the class with his solar gain and retention and he got help with his Dad on that.
>
> **Leo**: Yes, with the idea with the oil.
>
> **Bridget**: Yes.

Clearly, Bridget considers Clarence's way of engaging in the Solar House project to be a continuation of a viable approach which was already well established. The metaphor of "going down little side roads" helps to describe the natural tendency of many students, especially those who have already found ways to be successful, to extend their thinking beyond the pathways available in the regular curriculum. I think it is important to note that Bridget provided many students including Clarence opportunities to "go down side roads" of interest for them during the Solar House project. It is another example of her capabilities as an excellent science teacher.

Role of curriculum/text in action-thought

However, even good science teaching may not be enough to win over the hearts and minds of students. The curriculum with its associated materials and activities also plays a part. My perspective in the Solar House and Invent a Machine projects was not entirely the same as

Bridget's. I had a sense that some students were more likely to make a critical comment about their learning activities to me rather than to Bridget.

One reason why some students took the opportunity to speak in an open and sometimes critical manner with me about their science learning may have to do with a fundamental difference in the way I was situated in the classroom as compared to Bridget. She was responsible for determining their grade whereas I was not. Students knew that I would not be involved in their assessment and I consider this aspect to have been an important component to being able to have meaningful conversations with them. Perhaps this aspect of my research approach would not have been so important if Bridget had not included a competitive component in her assessment approach. However, given the assessment approach that was used in the Solar House project I believe that not becoming involved in the grading of student work increased the complexity of the interviews I had with students.

A second reason has to do with how committed students perceived me to be to the curricular activities. How open or critical would a student be during a conversation with me if they perceived the activities they were commenting on to "belong" to me? The design and implementation of the curricular activities was an area in which Heidi and I interacted with Bridget but as far as the students were concerned, Bridget was in charge of their activities.

A third reason is that students have a lot of relevant and worthwhile things to say about the nature of their learning environment. Students rarely get the opportunity to speak with an adult about the nature of their classroom learning experiences. When an adult demonstrates an interest in their ideas they are usually very pleased to respond in depth.

Clarence was a good student who did excellent work. From Bridget's perspective, it appeared that Clarence was enjoying science as much as anyone could and he enthusiastically took advantage of wide latitude she gave him to explore his own ideas. However, Clarence was not completely happy with everything he was doing in science and his experiences in the Solar House project and the IA Technology class provided a backdrop to criticize his engagements in some of the curricular activities. In the course of my interview with Clarence he decided to tell me about an open-ended investigation involving the construction and use of a device for chemical distillation which he had conducted with other students in the IA technology class. How he considers this kind of engagement to be different from the activities provided in the grade nine science curriculum is as follows:

> **Clarence:** Well, I can tell you what a whole lot of people like was fire, not just the Bunsen burner flame but the other flame and that **we actually created something**. If you mix chemicals you can predict the result, with this they told us we'd have something in the bottom here but ... **In the chemical unit** when you created different substances and stuff, **they tell you what it's going to create** ... In this they didn't really tell us what we were going to make and you could see the layers of the different substances and we learned what is actually in wood and it's just an interesting, neat experiment.
>
> **Leo**: And you also told me that you bent some glass.
>
> **Clarence:** Yeah, well we had to construct first of all the little flame thing.
>
> **Leo**: Is that something you consider important?
>
> **Clarence:** Well, not really but I haven't bent glass in a long time so it was fun. It's more fun than just being handed the materials " **Here, do the experiment and we'll move on**. "
>
> **Leo**: So, if we could just return to some of the activities that you were just describing to me from the grade nine textbook.
>
> **Clarence:** And not told what the results are going to be and maybe add a little bit. You see, that's the added bit, the flame. We created essentially our own oil rig. So it was interesting. **We didn't know what was going to happen**, we just went ahead and did it.

Clearly Clarence makes a distinction between the prescriptive nature of textbook activities and the proscriptive quality of open-ended investigation. My conversations with Clarence and other students revealed that many of the students in the Solar House project consider their textbook science activities to be uninteresting and "cooked" to produce a particular pre-specified or known result.

An effective context for thinking has both an epistemological and an ontological dimension. While the nature of the epistemological dimension (i.e. conceptual knowledge and associated activities) implicit within the junior high science curriculum may not have changed substantially since it has been implemented it may be the case that there has been a more dramatic shift in the ontological dimension (i.e. the way people experience or interact with curriculum). The nature of what a student "learns" may be somewhat similar today to what it was years ago but the nature of how he/she "thinks" about and engages what is being "learned" may be quite different. In other words, the "shape" of a student's engagement with her/his learning environment has been shifting toward a more proscriptive orientation .

A reason for an ontological shift in student thinking may emerge from their perception of how teachers engage and participate with students in exploring the curriculum. Students seem to be able to notice if a teacher is genuinely interested in the phenomena associated with the activities in a curriculum. What happens to the level of a teachers engagements with the same phenomena after experiencing it in the same way year after year? What happens to a student's cognitive level of involvement if they perceive the teacher to be guiding them along a prescribed pathway in a pre-established activity as opposed to navigating uncharted territory in a dynamically changing activity?

A shift toward embodied and proscriptive forms of assessment

A shift toward more embodied and proscriptive approaches to assessment involves essentially two things: involving students in the assessment process and giving a broader consideration of what counts as being worthwhile in a student's learning engagement.

Epistemological developments such as learning specific concepts seem to occur on rather long time scales (i.e. several months/years) for students. It may be the case that the emergence of ontological change (i.e. discovering new ways to participate effectively in a world) occurs on a much shorter time scale (i.e. days) and is therefore more appropriate as a way of assessing viability. If this is the case, and I think it is, then focusing on how students engage their world is a pedagogic technique which is just as important as one that focuses on what students know about their world.

There was a progressive re-shaping of Bridget's involvement in the Solar House project as she attempted to construct an effective approach to evaluating student understandings. The Invent a Machine project provided Bridget with an opportunity to continue developing complexity in her approach to assessment in an action-oriented science learning environment. In a sense, the Invent a Machine project was an occasion to recursively re-enact her understandings of an effective process oriented approach to assessment.

In the Solar House project Bridget began with an assessment technique based on constructing a rank ordering of students' achievement based on the outcomes of a scientific test. This was a technique with which she was familiar. It is commonly used in science classroom building projects and Bridget used it in both the Ice Cube and Solar House activities. The approach can be summarized in synopsis form by the following sequence of student and teacher actions:

1. Students plan and sketch a device (i.e. Solar House or Ice Cube Insulator).
2. Students build the device.
3. Students use the device to conduct a scientific test and obtain a result in quantitative form (i.e. fraction of ice cube preserved in solid form or area under a heating cooling curve).
4. Teacher constructs a rank ordering of performance results for the devices.
5. Teacher assigns grades by organizing the rank ordering within a range of minimum and maximum scores (e.g. 70% - 100%).

Bridget also evaluated the work that the students produced for the written assignments she gave in both the Ice Cube and Solar House projects in order to construct an overall evaluation of each student's understanding. Given that the Solar House project was a culmination to a unit of work, Bridget's assessment was essentially an evaluation of each student's understanding for the entire unit on Heat and Energy. One reason why many teachers use this approach is because it seems to encourage students to remain "involved" throughout a project because of the high degree of anticipation that builds as they work toward obtaining a final result. That was certainly the case in the Solar House project.

My concern with this approach is twofold. First, this assessment approach encourages students to place more emphasis on the outcomes of their work rather than on the action-thought processes they use to obtain results and/or their developing depth of understanding of the scientific concepts learned. This is inevitable given that student anticipation builds progressively toward a final release. Second, the competitive atmosphere that is an explicit part of the design of this assessment approach can have unintended outcomes in that some students may interpret it as an incentive to avoid interacting and collaborating with their peers.

As the Solar House project developed Bridget began to add complexity to her approach to assessment. As her engagements with students' ideas-in-action grew in significance she became interested in knowing more about how her students were interpreting the task and thinking. The reflective writing worksheet (see Appendix B) was developed by Bridget in collaboration with me toward the end of the Solar House project. It represents a shift in emphasis toward a more process oriented assessment approach. It provides students with an occasion to formally describe some of the meanings their engagements hold for them. In addition to providing me with research data, it allows a teacher to engage in a second-order form of interpretation of student thinking and understanding in the sense that the focus shifts toward how students think about their learning experiences and away from what students accomplished in those learning experiences. Reading her students' responses to the reflective writing worksheet seems to have helped Bridget extend her understanding of the kinds of things that she considered to be worthwhile incorporating into her assessment approach. After reading the responses of students in the Solar House project to the reflective questions she commented as follows:

> **Bridget**: ... I really found it helpful for me personally to read their responses to the reflective questions. Most of the kids responded very thoughtfully and I got a lot of information about good teaching from their responses and insights into the kids too, kind of the process they used.

Bridget continued to shift her assessment focus toward a more process oriented perspective in the Invent a Machine project . There was an increase in diversity and complexity to the occasions she provided for students to enact their understandings of science concepts and the processes they developed to understand those concepts. The sequence of engagement is now as follows:

1. Students choose their own way of entering the task (e.g. drawing a plan, conversation with Leo or Bridget, working with materials, watching/helping other students build). Students who wish to do so submit a plan (e.g. sketch or description) but they are not required to do so before they begin working with materials. Students who like to draw are encouraged to develop several sketches of their ideas.

2. Throughout the building process, students give impromptu demonstrations, visit and interact with other people and workspaces, conduct repeated informal tests, and develop criteria to determine the success of their work.

3. Students conduct a formal oral presentation for the entire class in which they demonstrate their machine, explain the criteria they have developed for evaluating it, point out where simple machines can be found in their device and explain how energy is transformed as their machine operates. Other students observe, ask questions, and acknowledge the presentations at their conclusion with applause.

4. Students provide a written description of their work (including a final sketch, a flowchart, and an explanation of energy transformations).

5. Students provide written responses to the reflective worksheet.

6. Teacher assigns grades based on the quality of the written and oral presentations and the skillfullness incorporated in the machine.

As described in Chapter 7, Students developed their own evolving set of criteria for adequate conduct as they worked in the Invent a Machine project. In a classroom presentation, each group of students explained the goals they had set for their machine and described how well they had been able to meet those goals, including the difficulties they encountered. Students also wrote reflective accounts of their experiences in designing, building and testing their machines. Perhaps a move toward a more embodied approach to assessment is a natural outcome of allowing students to become more involved in the shaping their problem environment.

Compelling evidence of the emergence of Bridget's expanding world of significance is connected with her sense of her relationship with her students. At the end of the Solar House project she commented as follows:

> **Bridget**: ... my relationship with them really changed. I think that part of it was to whatever extent that they seemed to blossom during the open-ended project. I don't know that it is cause and effect but the two went hand and hand and I enjoyed teaching them more and more and they seemed to get more on track in science.

Bridget seems to be describing a coemergent relationship between her relationship with her students and their abilities to engage in effective action-thought. The theme of coemergence appears at multiple levels. For instance, Bridget also noticed a coemergent relationship in the various processes that students used to engage in effective action-thought.

> **Leo**: ... Do you have a sense that some kids plan it and then do it or do some kids do it and then get some ideas out of that? How does it move along for the kids?
>
> **Bridget**: I don't think that either/or ... I think it's both/and ... I think that ... in no way did they say "Ok first we're going to control this variable and then we did an experiment and saw the results" or "Ok, so we're going to make sure our house has this and now we're going to control this variable". I mean that didn't happen at all and I guess **I realized the futility of trying to structure process, that process doesn't happen in a linear way**. I mean it's just kind of like an army marching through a swamp tackling all things on all fronts at once. A lot of the way that we teach science ... when you try to make it linear it is so counter-intuitive or counter-productive ... counter-something or other.

Clearly, Bridget's thinking about the nature of her teaching was connected to her experiences of the nature of her students learning and her own learning. Heidi and I invited Bridget to read a paper that we had written and presented at a conference. It described many of the theoretical ideas from enactivism that we considered to be important to our emerging understanding of the nature of students' thinking in the Solar House project. I think it is worth noting that some of the enactivist ideas we presented in that paper also resonated with Bridget's experiences in teaching science. The following excerpt illustrates one component of an enactivist perspective to learning/teaching that she considered to be especially noticeable during the Solar House project.

> **Leo**: You had a sense that the students were thinking a little differently as the project got started, as they got a sense of the open-endedness of the project and the sense of the way that you were going to interact with them on the project?
>
> **Bridget**: I think that's part of it. I think the nature of your interaction with them and my changing interaction was part of it but what you talked about in that paper, about you know, Dan catching-on and kind of seizing some aspect of that experiment. I think that happened with these kids as well. **I think they seized upon a part of their experiment that was unique** and they ... they either ... believed it would be successful or just having attachment too ... maybe the two went together. They had an attachment to that part of the project, to their idea, and believed it would be successful.

An enactive classroom is a proscriptive learning environment because it encourages students to develop and pursue their own pathways for viable action-thought. Trajectories of action-thought are often qualitatively different for different groups of students. When students become personally connected to and involved (i.e. embodied) in a problem setting they become aware of their own ways of bringing forth and engaging a world of significance. An enactive approach to learning/teaching is open in the sense that it nurtures the pursuit of thinking and the emergence of understanding as processes of recursively broadening an affordance space. Every pathway of action-thought that is visited and re-visited contributes to a deeper and more complex understanding of the problem setting and one's way of being engaged with the problem setting. The enabling power of an enactive learning/teaching experience emerges from the experience of extending the domain of ones world of significance.

It is significant that Bridget continued to engage her students in extended building projects well after the Solar House and Invent a Machine projects had concluded. In the second interview with her two years after the Solar House project she described her engagements with my supervisor and myself as representing a kind of epiphany in her thinking about pedagogic practice .

It was not an objective of my research engagements to change the nature of Bridget's approach to teaching science. However, it is evident that Bridget does consider her approach to have changed as a result of her interactions with us and her interactions with her students. Perhaps a research approach that focuses on the nature of student thinking in the context of a classroom offers a viable way to encourage other science teachers to develop new approaches to their teaching. One enactivist theme that Bridget continued to emphasize in the second interview has to do with the way she felt that was able to participate with her students as an active learner.

An essential component of an enactivist learning/teaching engagement is the sense of wonder which permeates the atmosphere of a problem setting. When a teacher engages in action-thought in such a way that it expands the complexity of their own thinking , it also contributes to an expanding world of significance for students.

Adequate conduct and assessment

The process a student enacts in developing understanding often reveal meanings that are not often allowed to emerge in traditional approaches to assessment. Assessment is generally designed to constrain students' action-thought trajectories within epistemological boundaries established by the conceptual understandings of what is being taught. What is an appropriate pedagogic response when a student's process of developing understanding leads to the emergence of an action-thought trajectory that diverges out of the bounds for adequate conduct established by the assessment strategy? The issue at stake has to do with who controls the agenda for establishing adequate conduct. If we are to remain committed to the constructivist notion that students can and do create their own meanings and processes for developing understanding then we must also commit ourselves to respecting the kinds of meanings and understanding processes that students enact.

One example of a case where this became an issue occurred in the Solar House project. Erin was perhaps the least visible student in the classroom. She tended to sit off by herself in a back corner of the classroom and seemed to prefer working alone on the activities that were done. She was frequently absent and rarely participated in classroom discussions. She did not seem particularly interested in science and whenever Heidi or I would sit down to talk with her she seemed most interested in showing us a drawing from art class or a new poem she was working on. In short, there were things other than science that had captured the "lions' share" of Erin's interest. Heidi and I wanted to find out what Bridget's perceptions were of the kinds of meanings that emerged as being significant for Erin. Our conversation about Erin's involvement in the Solar House project developed as follows:

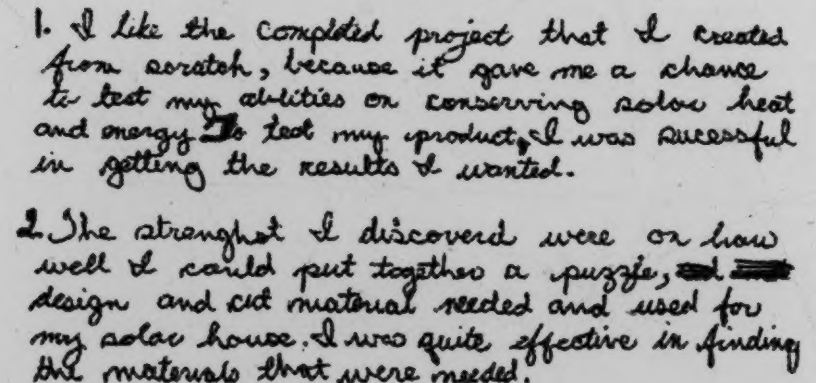
> **Heidi**: ... We are trying to get a sense of the diversity of how kids function when they have control over what they do. There is the option for some of these kids that the control becomes a case of progressive disengagement. In other words, if you truly give people control then maybe one of the options is that they can decide is that they are really not into this. Can you comment?
>
> **Bridget**: I think you probably had more contact with her [Erin] than I did. ... She hasn't been an active learner, but she did create a design that she was proud of and she showed me all of the details. I think she used a milk carton, a two liter milk carton, did she? Did she have an angled flap in there as well?
>
> **Leo**: I remember seeing it after it was finished and it was sealed and I remember you commenting about it as I was looking at it at the same time, as she was introducing it to us ... There was no way in or out of this house, it was a sealed house, and it had sort of a caulking or a silicon sealing the windows.
>
> **Bridget**: I think ... Erin is a girl who writes a lot of poetry. I mean she writes poetry all of the time and I think what appealed to her about doing the project was the aesthetics about it and I think that she liked the look of the design. I think it was secondary to her how well it gained solar energy or retained heat. **I think it was a chance to create something that she liked the look of.** ... And that [testing her solar house] seemed kind of secondary to her anyway. I don't think it was really the function of the house that was most important. It was the form of it.

However, what is important is that Erin considered herself to have been successful in building her solar house. Erin got a late start on the building project because she missed several days due to illness and so she did not finish her solar house until a few days after everyone else had completed testing their houses. When she did finish building her solar house, Erin proudly showed it to me along with the illustrations she had made. Her house was essentially a styrofoam cube, smaller than most of the other solar house designs, and was completely sealed with silicone. She told me that she had done most of the work in the IA technology classroom and she was clearly proud of the quality of her workmanship, especially the small (approximately 1 cm by 1 cm) glass window she had incorporated. I do not have a copy of the diagram Erica drew of her solar house although a video image of the drawing exists.

Erin's participation in the Solar House project did not seem to have much affect on her position among her peers in the classroom social-cognitive structure. I think she preferred the fact that she conducted the test of her house separately from the others. Completing the construction of her house was the event that seemed to be most important for her. Table 9 presents excerpts of Erin's responses to the written reflection worksheet.

Table 9

Excerpts of Erin's written reflections



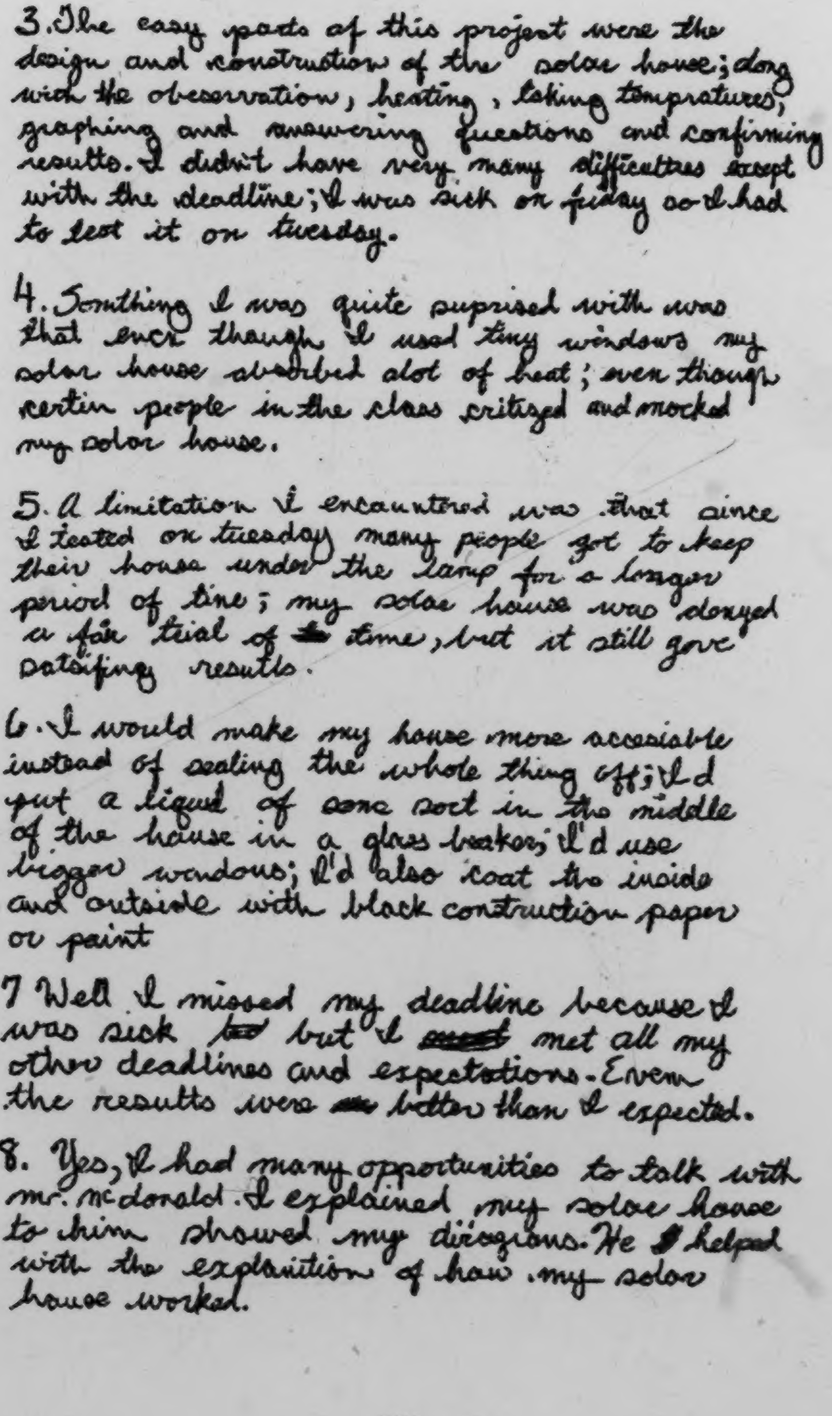
1. I like the completed project that I created from scratch, because it gave me a chance to test my ablities on conserving solar heat and energy. To test my product, I was successful in getting the results I wanted.

2. The strenghst I discoverd were on how well I could put togethor a puzzle, design and cut material needed and used for my solar house. I was quite effective in finding the materials that were needed.

It is important to note that Erin considered herself to have been successful on this project, something that Bridget said had not often occurred in Erin's previous science engagements. It was difficult for Bridget to have much interaction with Erin because of the amount of class time she missed. The completion of the solar house construction provided Bridget a rare chance to sit down with Erin and listen as she described the various parts of her house. In a sense, the solar house project provided Erin with an occasion to discover new strengths about her own capabilities to build a scientific device and to share them with Bridget. What was adequate about Erin's conduct in the Solar House project had little to do with the performance of her house in the test and much more to do with the opportunity to reveal capabilities in science that she had not shown to Bridget before. Table 10 presents more excerpts of Erin's responses to the written reflection worksheet.

Table 10

More excerpts of Erin's written reflections



3. The easy parts of this project were the design and construction of the solar house; along with the obeservation, heating, taking tempratures, graphing and answering questions and confirming results. I didn't have very many difficulties except with the deadline; I was sick on friday so I had to test it on tuesday.

4. Somthing I was quite suprised with was that even though I used tiny windows my solar house absorbed alot of heat; even though certin people in the class critized and mocked my solor house.

5. A limitation I encountered was that since I tested on tuesday many people got to keep their house under the lamp for a longer period of time; my solar house was denyed a fair trial of ~~the~~ time, but it still gave satsifing results.

6. I would make my house more accesiable instead of sealing the whole thing off; I'd put a liquid of some sort in the middle of the house in a glass beaker; I'd use bigger windows; I'd also coat the inside and outside with black construction paper or paint

7 Well I missed my deadline because I was sick ~~to~~ but I ~~[illegible]~~ met all my other deadlines and expectations. Even the results were ~~[illegible]~~ better than I expected.

8. Yes, I had many opportunities to talk with mr. Mcdonald. I explained my solar house to him showed my diagrams. He ~~[illegible]~~ helped with the explanition of how my solar house worked.

A second case in which the issue of adequate conduct arose occurred during the Invent a machine project. One student in particular, Allan, was a bit of a mystery to me and to Bridget because it seems he decided not to construct anything, at least not anything in the classroom. Allan was the only student who announced that he needed to work at home where he said he had everything he needed to build his machine. Bridget decided to respect this decision after he promised to produce a video presentation of his completed machine. When either Bridget or I made inquires about how his machine was progressing Allan seemed to always describe new developments. He described the machine he was designing as a device designed to mechanically switch a television on and off from a distance. We tried to encourage Allan to build in the classroom (i.e. provide a school television to work with) but he seemed uninterested in doing that. On one occasion, Allan and I worked together in the classroom to construct a system of weights and pulleys that would simulate what he was trying to accomplish at home. Although he seemed to lose interest in this exploration, explaining that it really was not the same as the machine he had at home, Allan did take a couple of pulleys when I offered them to him. I am not sure what he did with them.

Allan was present for each class throughout the project and was never disruptive. In fact, he spent nearly all his time interacting with other students and he seemed to make a number of productive contributions to the development of their machines. However, Allan seems to have managed to avoid all of our attempts to engage him in what we considered to be appropriate action. He seemed happiest when he was visiting and contributing to other students building projects. By the end of the project Bridget was still waiting to receive the video of Allan machine that he had promised to provide and he did not produce a written analysis. When I interviewed Allan he described for me in intricate detail how his machine worked and how much he enjoyed the project. After I described my interview with Allan to Bridget decided to inquire with his mother. It turned out that she had no knowledge of Allan working on any science related building project at home.

What are we to make of Allan's apparent decision not to build anything? Was Bridget's decision not to challenge Allan to provide clear evidence of progress appropriate? There is no easy answer to this question. Allan was allowed the freedom to establish his own criteria for adequate conduct and he seems to have done this by engaging and contributing ideas in other student's workspaces. Perhaps seeing many ideas develop and take shape was the level of engagement that Allan felt was most appropriate for him at that time. On the surface, Allan seemed to be very forthcoming and interested to talk with me and with Bridget about his work. However, the issue of whether Allan did or did not build a machine at home was left unresolved.

What changes for students and for the teacher when they engage in an enactive learning/teaching environment? As a previously established social-cognitive hierarchy among the students is diminished, opportunities arise for other less visible students to be successful and to be perceived as being successful by others. The variety of ways in which one can be successful opens up, creating a richer and more interactive learning environment. Students and teacher learn from each other and learn about each other in a way that is not possible in more structured, top-down activity in which pre-specified outcomes are to be met. When the classroom learning environment changes, the ways that students seek to engage the environment changes. The network of communication pathways increases and becomes more complex as students visit, interact with, and experience the larger process that is enacted by the learning/teaching community as a whole. A sense of purpose emerges from the focused way that the community goes about "doing its thing".

For the teacher, teaching becomes listening. Teaching becomes stepping aside and allowing the students to lay down their own paths rather than saying "Come this way, follow me, follow me". Teacher-student conversations become conversations about the student's ideas and the possibilities they reveal, rather than about the adequacy of their progress or the accuracy of their results. As the learning/teaching environment grows in complexity so does the nature of the assessment . Students become more actively involved in establishing criteria for their own adequate conduct and what constitutes adequate conduct becomes more holistic and process oriented for everyone.

Chapter 9: Discussion and Implications

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time *(e e cummings)*

I have tried to study "knowing in the making" in two ways. One way is grounded in an enactivist view of cognition which implies that knower and known mutually specify each other. Knowledge is neither uncovered nor invented - it emerges in the mutually specifying dynamic of the actions of the person and the qualities of the environment. I have portrayed the enacted "dance" involving the knower and the known as a physical one involving the emergence of embodied ideas, actions, and physical constructions. The vignettes and the surrounding discourse presented in the preceding chapters reveal some of the diversity and complexity of this process of "making understanding" in science learning contexts.

A second way of viewing the study of "knowing in the making" has to do with the conditions under which the process of making understanding is studied. I have sought conditions where I could observe and participate in this process in a manner similar to what biologists refer to as *in vivo* (i.e., as it occurs in a natural setting) rather than *in vitro* (i.e., under controlled and pre-specified conditions). In education the term *in vivo* can imply a number of things. It is not enough to say that the *in vivo* quality of my research emerges from its being situated inside science classrooms, although that is a part of it. The key element here is that in the process of becoming a part of the community which I was attempting to study I was "acting with" the community in collectively "laying down a path by walking". Similarly, one could not predict precisely what Amy, Keith, Dan, or any of the participants in this study would do next based on what she/he had done before. What could be said, however, was that as self-organizing and cognizing beings, each would find a viable path.

Reprisé

What is meant by knowing and understanding ultimately rests on the conception of mind and the theory of cognition that one holds. I have chosen as the basis of my interpretations the enactivist position that knowledge cannot be separated from the knower (Kuhn, 1970; Polanyi, 1983; Maturana and Varela, 1987). I take as a premise that cognition is embodied. I have looked for instances within the context of science classrooms that illustrate what we

can mean by some of the key ideas of enactivism e.g., coemergence, structural coupling, adequate conduct, and how these interpretations can inform learning and teaching.

Enactivism in its general form is a "grand theory" (Kuhn, 1970). It is presented by its developers as a kind of "theory of everything" in that it applies to all living organisms. The theory of enactivism itself is open to the same questions that can be mounted to challenge any theoretical position of wide applicability. Among these are questions surrounding language. Enactivist theory is presented in ordinary language, hence the meanings of the terms are open to multiple interpretations. A second question has to do with ontology. Is enactivist theory metaphorical, and if so, what difference does it make?

Enactivism can also be viewed in a more specific context, namely as a way of interpreting human engagement with environment. In this chapter I will describe some of the limitations of enactivism as an interpretive framework for action-thought that have become apparent to me as I have used it in the course of this study.

My research focuses on portraying the nature of thinking in action. Central to my thesis is the question of how students create meanings for themselves in complex and evolving building environments. How do students construct meaning and understanding when they experience a high degree of physical engagement in building things? How is understanding enacted in such a setting? How does the shape of a problem emerge? What are some of the characteristics of an enactive learning/teaching environment?

I have explored how developmental building tasks in science are enacted in a variety of contexts. A schematic representation of the sequence of my research engagements is presented in Figure 36.

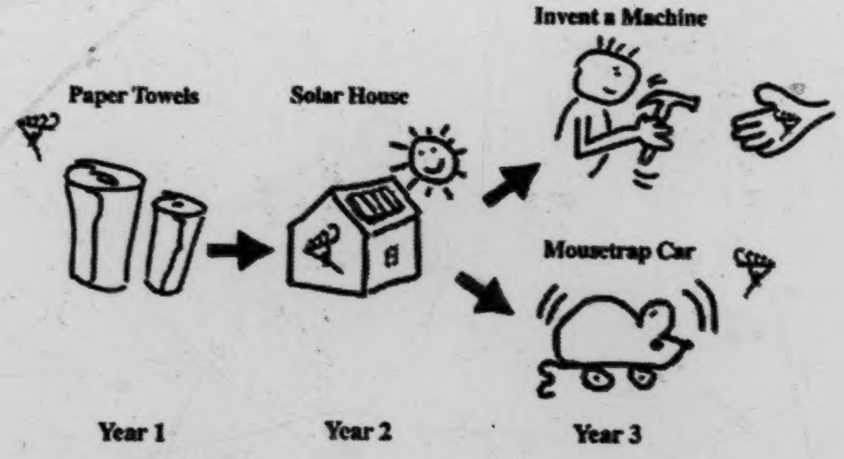


Figure 36: Sequence of my research engagements with students

Keeping in mind that "everything said, is said by someone", I have included myself (eye or eye/hand) as observer or observer/actor in each representation. I have chosen an external "eye" as the "observer icon" associated with the **Paper Towels** and **Mousetrap Car** projects in order to depict my role as mainly that of an observer of students' work. The "eye" is situated inside the **Solar House** project in order to depict the increase in my participation in the development of students' work during this component of my study. Finally, the "eye" is situated inside a hand in the **Invent a Machine** project in order to describe my role as an observer-in-action and the co-participatory nature of my engagements in students' work during this part of my study.

The common thread in these projects is that students are given wide latitude to interpret the nature of the task and to improvise their sequence of engagements in order to create a viable response. While there are variations, my fundamental unit of analysis is persons-acting-together-in-a-setting. I regard setting as a complex evolving entity co-created by students, the tasks, the teacher, and myself which taken together constitutes the environment in which understandings emerge for everyone involved. The understandings which emerge depend on the various individual and group (i.e., class) histories of structural coupling which are brought forth and interwoven into a complex web of meanings. Each person's understanding is unique and self-determined and yet it is also dependent on the emergence of a community of meanings. Participants are not only aware of the emergence of their own meaning in action, they are also aware of the emergence of multiple other meanings among the members of the group. Understanding is not only contextual, it is also communal, and building may be viewed as participating in a kind of story telling. I will return to this point later in the chapter.

My results are presented in a combination of interpretive vignettes, interview segments, selected student diagrams, and student and teacher accounts describing and interpreting their experiences and creations. I will now revisit my research questions and respond to them on the basis of the descriptions and interpretations of my study.

A response to my guiding questions

Knowledge building processes are developed and used by students on many overlapping and interacting social-cognitive levels within a science classroom in which freedom of action is encouraged. My research questions are constructed in a way which allows me to address issues concerning the nature of knowledge building processes from various perspectives.

The four questions which I presented in Chapter 1 and around which I will now construct a summary of my research findings are as follows:

1. How is understanding enacted in building activity?

I have observed that processes of problem articulation and management are mutually specifying in nature, with progress toward outcomes taking on both strategic and recursive elements. In an enactive learning/teaching environment the relationships between students and the teacher may be described as an "extended conversation". A conversation implies a consensual coordination of action. Students seem to move spontaneously and recursively between (apparently) turbulent periods of free exploration and interaction with tools, materials, and themselves and somewhat more focused periods in which construction and organization of ideas takes shape. Students seem to be quite willing to discuss and defend their ideas when they actively develop their own processes for creating and testing them. Furthermore, a student's perspective on what he/she is doing seems to change as his/her understanding evolves. Students tend to consider themselves as "being **in** the investigation" as opposed to following externally presented steps outlined in textbook laboratory activities.

2. How does the shape of a problem emerge in building activity?

The shape of the problem is a metaphor for describing a complex set of meaning making processes. A problem acquires its shape only when it becomes embodied in the sense that it is taken up by a person acting in a setting.

Students do not use, or quickly abandon, the investigative sequence known in school as "the scientific method". Rather, they conceive their own investigative strategy and engage in a complex and recursive process of planning and action. Self-conceived processes of scientific investigation appear to be more viable and stable than processes of directed activity in contributing to the development of students' understanding. For instance, Dan and Tristen stated quite clearly that they did not consider the "scientific method" as they understood it to be useful or necessary for them to proceed in a satisfactory way during the **Paper Towels** investigation. In, the **Solar House** and **Mousetrap Car** projects, Dan and Tristen did not even talk about the scientific method. It seems that they did not consider it to be relevant to their explorations in those projects. Instead, they developed their own approaches for engaging these problem settings.

There was a discernible progression in the qualitative nature of Dan and Tristen's approach to action-thought over the three projects in which they were engaged during this study. In the **Paper Towels** project they seemed to focus on exploring until they discovered **one way** to succeed. They did not seem interested in exploring alternative ways to solve the problem. In the **Solar House** project Dan and Tristen were interested in alternative ways to address the problem. However, their apparent attempt to maximize the complexity of their design seems to have contributed to an approach which involved a long process of constructing one design followed by a single culminating test. In the **Mousetrap Car** project they were not only interested in multiple design approaches, they had also developed a way to explore several possibilities (i.e. a recursive approach of rapidly building up and tearing down). There was a noticeable increase in how quickly they were able to incorporate new ideas into their construction and in the number of different construction designs they tried (a similar evolution emerged in the **Invent a Machine** project e.g. Tim and Mark, Tony). There was a discernible cycle of inventing and testing that had not been so explicitly present in the other projects. It seemed as if there was more emphasis on exploring alternative design possibilities than before. Action-thought seems to acquire considerable momentum and complexity when: (1) adequate time is provided, (2) a recursive element is present, and (3) focus shifts toward realizing multiple potentialities rather than a single outcome.

Some students consider their actions to be more "scientific" when they incorporate more complexity whereas others strive for simplicity, perhaps reflecting the tension that exists between these orientations in science. In Dan's case, there was a noticeable change in his approach to innovation and testing as he discovered new significance in the value of incorporating simplicity, as opposed to complexity, into his approaches to design, building, and testing. By the time he had finished his grade twelve physics course his commitment to this approach had grown in significance with the incorporation of a strategy aimed at breaking a problem down into component parts. It seems that a students' appreciation of how simplicity or complexity of an approach to action-thought contributes to the development of her understanding may play an important role in allowing her to modify her approach. In addition, it seems that gaining an appreciation for the simplicity or complexity of an action-thought approach requires multiple experiences in open investigative environments which incorporate design and building activity.

The degree to which students become involved in each others work seems to depend on how they consider themselves to be implicated in determining the criteria for success. When students are involved in determining their own criteria for success, such as in the **Invent a Machine** project, they seem to be more interested in co-participating and collaborating with others. When external criteria are imposed (i.e. by a teacher), such as in the **Solar House** project, then students tend to pay little or no attention to investigative processes used by their peers until the assessment stage of their project work. It seems that the shape of the problem is strongly influenced by the degree to which students perceive a problem to have open-exit qualities as well as open-entry qualities. In addition, the openness of the social dimension of the problem environment plays a role in shaping the problem for individual students. There seems to be an increase in students' capabilities to be self-maintaining in their action-thought when they co-participate in open collaborative environments (e.g. the classroom environment in the **Invent a Machine** project).

The shape of the problem seems to have a plastic quality in that it emerges in action. In the case of Dan and Tristen, the approach for developing an answer to the question posed in the **Paper Towels** investigation emerged after an extended period (several minutes) of free exploration with the materials and equipment provided. The **Solar House** project seemed to have a more rigid quality. Perhaps this was connected to the "all or nothing" approach that Dan and Tristen adopted in this project. In contrast, the **Mousetrap Car** project seemed to have a more dynamic quality that allowed more opportunity for innovation in design and approach.

The plasticity of the shape of the problem is significant in that it seems to play a role in students' capacities to engage in meta-cognitive reflection. Dan and Tristen began to make distinctions in the way they were engaged in the projects only after they were engaged in the **Mousetrap Car** project. In the **Invent a Machine** project, the students who seemed to be most able to provide insight about their thinking during my conversations with them seemed to be the same ones who were deeply immersed in bring forth a path in doing. It seems that students who enter into and become fully implicated in enacting their understanding are able to emerge from the process and reflect on it from a distance, metaphorically speaking. In other words, bringing forth significance in "doing" seems to allow one to simultaneously bring forth significance in "thinking about what one is doing".

The shape of the problem has a multidimensional quality in the sense that it seems to have interacting microscopic and macroscopic properties. For instance, on a macroscopic scale, Tony seems to have transformed the **Invent a Machine** project into an opportunity to experience aspects of his father's engineering world. On a microscopic scale, he was recursively exploring ways in which materials and equipment could be shaped and reshaped into an organization of interconnected structures i.e., his enactment of a machine. In a sense, he was inventing a way to explore a culture or world of significance brought forth by his history of structural coupling. In Tony's case, the plastic quality of the shape of the problem emerged in the multiple possibilities he continued to bring forth and explore. The shape of Tony's problem was also plastic because he seemed to want it to remain unfinished. In other words, the problem shape was plastic because Tony was himself searching for new pathways of action in his desire to bring forth and experience new worlds of significance. The shape of the problem was partly determined by the embodied nature of Tony's involvement in the invention process and he seems to have extended aspects of his understanding of the shape of the problem into the evolving machine he was building.

While the shape of the problem appears to "drift" as new significance is brought forth, it seems that it may be important for a student to maintain some level of embodied connection to the shifting shape of the problem if he/she is to maintain a viable path of action-thought.

As noted in Chapter 6, Dave and Johnny seemed to "lose touch" with the shape of what they had been doing and, as a consequence, lost their sense for the possibilities of where they could go next.

The shape of the problem seems to be connected to the social complexities of a problem setting. In the case of Ian's **Mousetrap Car** project, it seems that the most significant "shape" which unfolded for him was related to the social interactions between himself and his brother (Graeme), between himself and his father, and between himself and the other members of his group. In this case, the evolving "social " shape of the problem allowed Ian to gain confidence in his ability to be successful in science because it required him to manage a complex set of social relationships.

3. How do students construct meaning and understanding when they experience a high degree of physical engagement in building things?

Physical engagement, at some level, is essential in the development of understanding. My study has revealed many instances of students constructing meaning in action. When students are allowed to improvise their own ways of acting they tend to include an element of risk taking in their approach. One way that students do this is by striving for physical complexity and sophistication in the structures that they build. A second way is to expand the realm of scientific concepts included in their creations beyond the information present in the curriculum. Both approaches are implicated in the emergence of a personal position within the culture of the classroom. Students are capable of being highly inventive in choosing materials and establishing ways in which they open up possibilities for developing understanding. Building is a process which allows a person to "envelop" and "be enveloped by" the evolving problem. It may be described as a process of self reorganization involving the embodiment of affordances from the environment. In other words, building is both a mental and a physical process. The key to developing understanding is not only in transmitted knowledge. Yes, its quality is important, but it is what one does with it and how one connects oneself to it that is central.

4. What are some characteristics of an enactive learning/teaching environment?

I have described some of the features of an enactive learning/teaching environment in Chapter 8. Such an environment yields a culture of doing and making in which individual action-thought and group action-thought are mutually specifying. Viewed collectively , the function of the group or class is to produce "works". Bruner (1996) maintains that the "works" or the artifacts, and progress in creating them, generate shared and negotiable ways of thinking in a group. I have observed the emergence of a shared purpose or coherence of action in the classes as students, teacher, and I worked together to develop and put ideas into action. Spontaneous instances of sharing, helping with, and participating in each other's work were numerous and contributed to an environment in which everyone learned with and, in a sense, taught with each other.

Bruner (1996) points out that the role of schools in "self" construction is very much a part of education. I noted earlier that building may be viewed as a kind of participation in story telling. There seems to be a narrative quality to action-thought when people build together in a cooperative setting and experience each other's unfolding stories. Narrative knowing differs from propositional knowing in that it seeks reasons, not causes (Bruner, 1996). Furthermore, it is embedded in context and culture. Stories deal not so much with events, but with what the events mean. These meanings are "open" in the sense that the reader or audience is complicit in their creation i.e., in bringing forth a world of significance.

The "self as doer" characterization emerged over and over again in my conversations with students. Over the time of my classroom engagements, I did not encounter a single instance of "disruptive" student behavior in the sense of discipline or classroom management. Furthermore, the teacher and most students seem to have had a similar experience. In short, discipline was never a significant issue; we all considered ourselves to be productively engaged. At times the noise level was high but the atmosphere was exuberant, "playful", and directed toward makings things happen. It was as if we were all engaged in an adventure - an adventure with rising anticipation, development, local setbacks, challenges, tensions, and resolutions. In other words, a coemerging story.

Interpretations of learning/teaching

What is revealed about the potential and place of building activity in the science curriculum and how does an enactivist stance toward the portrayal and interpretation of such activity inform questions of learning/teaching?

The question of "What is learned?" is an important one that ultimately goes back to the purposes of schooling and the balance or continually shifting position of equilibrium among three fundamental aims: the acquisition of knowledge and skills, the development and identification of personal capabilities, and the formulation of one's view of his relationship to and place within the larger environment. An enactivist stance seems to be successful in revealing aspects from a personal perspective of what is learned in making things. In creating and/or entering into a world of significance the person is learning about themselves as a person-in-a-setting. Such learning was described by students both in the sense of opening up possibilities for further action and in the sense of more abstract perceived personal capabilities such as willingness to take risks, willingness to tackle complex problems (e.g. Dan), or, as in the case of Ian, willingness to assume leadership.

If one recontextualizes the question as "What is learned through making things in science?" some interesting puzzles emerge. It can be argued that as a science education community we do not understand what students are learning in much of science because our models of curriculum, cognition, and assessment are restricted to a narrow set of outcomes and methods of assessment. In order to consider this question further, one needs to look at what is meant by "science" or, at least, "school science". Numerous analyses exist and I will not enumerate them here. Suffice it to say that in all but a few instances science is presented in school as if it is a freestanding structure of concepts, processes, and phenomena that, taken together, **describe** how the physical world "works". Students and teacher are both situated firmly outside this domain. Questions of "What is science learning?" and "How do I know when I am learning science ...?" are generally out of bounds.

Teachers such as the persons participating in my studies tend to view projects, particularly self-directed projects which require a related extended period of "in class" and "out of class" time, as culminating activities to units of work. There is an expectation that students will learn how to apply some of the facts, principles, and procedures of science in a coherent way to a practical problem. While the students may have learned about science principles, processes, and phenomena in the course of their building engagements, it seems the bases of my study that this is **not** the primary focus of their attention or conversation. Doing has an ontology and an epistemology of its own, one that does not invite overt consideration of the standard symbolic forms in which science ideas are expressed or which overrides such considerations with other ways of knowing. Student conversation was about specific actions and things, not about the theoretical ideas they had been studying. Teacher conversation shifted from monitoring how well the students understood the scientific principles involved to an eliciting of the students' **own** ideas. Both were, in a sense, now **inside** the problem.

How the teacher's evaluation approach developed in complexity as a result of her conversations and her engagements has been viewed from an enactivist perspective and is described in Chapter 8. The pervasiveness of the externalized view of knowledge taken by students is also illustrated. In Chapter 7 I have described qualitative differences in the nature of the sketches and the diagrams of their ideas that students prepared for themselves during "work in progress" and the more rigid, formalized, abstract diagrams submitted for the teacher in some final reports. These qualitative differences suggest that there may be some "inside-outside" cognitive/perceptual shifts involved in students' thinking when they engage in and describe their work in science. In my conversations with them, students (typically) described their work in representationalist terms even when their engagements were, from my vantage point, highly active.

Schon (1983) suggests a distinction between espoused knowledge and knowledge-in-action. Science assessments, current talk about performance assessment notwithstanding, emphasize espoused knowledge over enacted knowledge throughout most of schooling. It seems as if there is an assumption "out there" that high levels of espoused knowledge carry with them a knowledge-in-action component. Challenges to this view are beginning to appear (Gardner, 1993; Lave, 1988). The issue has importance, not only in an assessment context, but also in matters relating to curriculum. Curriculum, considered from an enactive perspective, may be described as a coemergent phenomenon i.e., what is learned is a function of the learner and how it is learned. The need for appropriate functional knowledge i.e., knowledge-in-action among school graduates is widely pointed out by educators, the business community, and the public at large. However, most assessment practice, including so-called performance assessment is restricted to performance which recapitulates actions and processes that the student has already (in a relatively narrow range) been shown how to do. The portrayals presented in this study indicate that a revelation of personal potential, abilities, and strengths is taking place (at least for some students) in a high action self-directed science learning environment. Students have told me that they are, in the course of their building activity, learning to deal successfully with complex and extended tasks within shifting contexts and that they consider themselves ready to take on more complex tasks. Such competencies seem to me to be desired outcomes of education.

If such learning/teaching environments are valuable, what can be said about their creation? Ms. B., in a final interview held more than a year after the **Solar House and Invent a Machine** projects had been completed was clear on this. It is very difficult for a teacher acting alone to sustain such levels of creativity for any length of time. The presence of one or more knowledgeable adult "resource persons" to interact with and facilitate student attempts to put their ideas into action is highly desirable. I did this during the course of the projects comprising this study as a way of being "inside" the problem setting. Members of the community, teacher aides, or other competent and approachable adults could, under appropriate circumstances, assume this role. Ways of enabling teachers to create such learning/teaching environments can perhaps be developed if it is pointed out that self-directed projects such as the ones described here are a "part" of the curriculum and not the "whole" curriculum, hence calling for person-resource support for finite periods of time.

Finally, the majority of the portrayals presented in this thesis are situated in "the present" in the sense of an occasion or a "place" in real time. Enactivist theory seems to be particularly suited to describing and interpreting action-thought "in-the-making". As such, it may have instrumental value in teaching. It has been suggested that in order to change teaching practice one does not need to look at changing the specific actions of the teacher. Rather one needs to look toward changing the **way** the teacher views learning and the learner in order to encourage significant pedagogic change. In this thesis I have used learning/teaching as a single semantic unit as a way of drawing attention to the mutual specification of the two components of the process. The language of enactivism is evocative and may have the potential to stimulate changes in the teacher's perspective of the learner and hence of teaching. Ms. B.'s perspective changed as her views of the capabilities and possibilities for acting with her students changed. The language of enactivism grew in significance for her pedagogic practice as she engaged in conversations with me and my supervisor over the course of the two projects and as she participated with her students in creating the learning environment.

There is evidence in my descriptions of our classroom engagements that a potential exists for the teacher to re-examine and possibly change her teaching and assessment practice when she views herself and her students as engaging in and co-creating a complex "conversation" or "emerging narrative". The teacher can now focus on her/his own learning within the culture of the classroom and hence become more open to a coemergent property in curricular events. Perhaps introducing the teacher to the language of enactivism is a way of starting the process. In Chapter eight, Ms. B. described how her perspective on pedagogy changed. As she put it, she found that she could at times "let go" of a teacher-as-authority role and allow students to develop their own pathways of action-thought. Enactivist theory implies that persons naturally attempt to engage their world in a way that allows them to be cognitively viable. Perhaps a more complex and productive cognitive environment can be brought forth in classrooms where the teacher and students co-create an emergent curriculum in which there are multiple ways to be successful (or viable).

Enactivism as a theoretical basis for the interpretation of learning/teaching

I have described a number of episodes which raise interesting questions about the ways in which students seem to use resources from their local environment as affordances to action. These resources include tools, materials, other persons, and artifacts created by others, and the dynamic of the culture of the classroom.

One way of describing the student learning environment is to locate these affordances within the environment. In the Varela, Thompson and Rosch (1991) sense, the structural coupling then takes place between the student i.e., the "organism" and the environment. Another way of describing the relationship implied in the term structural coupling expands and problematizes the notion of boundary between the organism (the student) and the environment. In the interviews with students during the Invent a Machine project I noticed many instances where students would hold their machine close to their body as they explained their thinking. It was if the machine had become enveloped as a part of themselves, a part that they were evoking in order to bring forth their descriptions of how they worked. The frequent occurrence of this phenomenon raises the questions of "What is coupled?" in the Varela, Thompson and Rosch (1991) notion of structural coupling and "Where is the boundary?" in the organism-environment relationship. Does a student remain separate from his environment or can he incorporate parts of his environment into his "self" in the cognitive sense?

Piaget suggests that it is a natural course for every organism to attempt to broaden the range of its influence over its environment. Varela, Thompson and Rosch claim that organisms naturally extend the range and complexity of their structural couplings with their environment in order to maintain their "fitness" or viability as their actions transform the environment in which they act. In a sense, Piaget and Varela, Thompson and Rosch are proposing similar growth processes. The episodes of student action-thought I have presented support the idea of a growth in significance for a student in her understanding of her relationship with her environment. They also lend support to the idea that "... mind is an extension of the hands and tools that you use and of the jobs to which you apply them" (Bruner, 1996, p. 151). When Tim and Mark (and Keith) described their understanding of their machines as being intimately connected to their actions and decisions in building the machines, they were, in effect, saying that their personal knowledge was embodied in the machine as a physical object and, conversely, that the building process itself in some sense enabled the machine to become embodied within themselves. In other words they are saying that they "are" the machine and that the machine itself "is" them. I consider this to be a remarkable insight from eighth grade students.

For instance, when Tim said "I have this memorized now. I could make a drawing of this after not seeing it for a long time and I could get every joint or piece ... in the right place. I have such a good feeling for it", he is describing how the machine has become embodied within himself in that he can reproduce it at will. Dan, in his final conversation, reflecting on his building experiences throughout secondary school science, expressed a similar insight at a metacognitive level. When asked about building Dan responded that the building process was now a "mental" process for him; a process that he enacted whenever he explored a complex problem setting. It appears that Dan's perspective on "making" evolved from one that portrays the body and mind as separate entities to one that views the body and mind as being part of a larger cognitive system. In so doing, he moves toward an enactivist perspective on knowing. Perhaps this shift is partly a consequence of his extensive experience in participating in school learning environments that incorporate open exploration and physical building as central components of the curriculum.

Enactivism essentially describes the world as constituted by two entities, a knower and a known. While enactivism allows for the sort of reciprocal relationship between the two entities i.e., organism (student) and environment that the previous examples describe, it does not allow for the possibility of either entity subsuming or being subsumed by the other. If an organism can, in some sense, incorporate aspects of the environment within itself, then this action implies numerous changes. One kind of change pertains to a change in the boundary between organism and environment. Varela, Thompson and Rosch seem to imply such a change when they describe knowing as entering into a world of significance.

Another kind of change could focus on the organization-structure relationship within the organism. Maturana and Varela consider the organization of an organism as the biological invariant. When the learner "accommodates" mentally, in the Piagetian sense, is it the organization that changes or is it the structure? Varela, Thompson and Rosch are not clear on this matter, perhaps because they do not provide us with enough appropriate examples to understand what they mean by "organism", "structure", and "structural coupling" when applied to cognition. It may seem that in the biological realm what constitutes an organism and what constitutes the boundary between an organism and its environment is relatively straightforward. Upon closer examination this is not necessarily the case. Mingers (1995) indicates that for human beings, Varela has proposed a model of the idea of "self" that underlies his development of enaction. The identity of an organism may be re-constituted in the autopoietic sense at levels of:

"1. biological (cellular identity)
2. bodily (immunological identity)
3. cognitive (behavioral identity)
4. sociolinguistic (personal identity)
5. collective (social identity)" (Mingers, 1995, p. 194).

A discussion of the implications of this five-level model of the organism is beyond the scope of this thesis. However, questions of complexity and of the properties of boundary between organism (however constituted) and environment seem in need of clarification in understanding the nature of the relationships inherent within and between levels.

Organizational closure of the organism does not imply interactional closure. The question of the boundary between the organism and its environment is important in matters pertaining to organizational closure. This requirement is central in Maturana and Varela's conception of autopoiesis, which they identify as a fundamental characteristic of living systems. Furthermore, while autopoiesis requires organizational closure, it does not imply structural invariance. Structures can and do change e.g., a seed growing into a plant. To use Maturana's term, structures can be plastic. The invariance of organization becomes problematic when an organism is able to incorporate aspects of its environment into its reinvented self. I have been arguing that one seems to be able to add, subtract, and modify, in some sense, the affordances which constitute our cognitive organization. It is not clear how an enactivist conception of organization, structure, and structural coupling help us to understand such capacities for shaping our selves in the cognitive domain. As well, our being as emotional and intentional organisms needs consideration in relation to key ideas of enactivist theory.

Creating a world of significance can be understood in terms of acquisition of knowledge. When we learn about the Incas or the structure of a sonnet these domains become more meaningful to us. When we make something we are not only learning **about** some thing, we are also learning to "**be-with**" the thing and to "**be-come**" the thing in the sense that we are now an embodied creator of something which is a part of ourselves that is also accessible to others. Understanding such enaction seems to involve ontological questions in addition to epistemological ones. A process of building is a process of invention in which a student not only enacts an affordance space and a way of engaging with that emerging space, but the student also "re-invents" herself as well.

The episodes I have presented illustrate the presence of a distributed component to action-thought. I referred earlier to a story-like quality of the action-thought which emerges from collective building activity. During each project it was often the case that several students would engage in periods of exploration with other students' constructions. These periods of exploration might involve watching others as they worked, manipulating aspects of their constructions, or helping other students as they invented their own devices. In a sense, the students engaged in a kind of shared and coordinated component of action-thought. Such a phenomenon is not considered in enactivism which views occurrences of structural coupling to occur between an organism and an environment. Perhaps one can better describe this type of pattern in terms of consensual coordination of action (Vygotsky, 1962). Language is clearly involved.

The notion of adequate conduct or viability of action is central to an enactivist position. Maturana and Varela take a proscriptive stance which connects the survival of an organism with the idea of adequate conduct. If an organism survives, then its conduct with respect to its environment is adequate. There are many organisms, hence many ways of being viable. This idea is attractive within the context of education in the sense that it allows for multiple criteria in considering notions of cognitive success. Attention is thus shifted away from the "correct" response or the "best way" to multiple ways of being successful in a setting, including making changes to the setting itself. The notion of "fit" can be used to refer to the complexity of the "shape" of the organism-environment structural coupling. While many trajectories of action-thought can be considered viable in the sense of being adequate, distinctions are possible in the "conduct" part of the idea of adequate conduct. In matters of cognition and the making of meaning it may be the shape of the structural coupling (i.e., the complexity of "fit") rather than its strength that emerges as a key factor. Interestingly, the same observation has been made in the field of cosmology (Zurek, 1996). The significance of a broader conception of adequate conduct became apparent to Ms. B (Bridget) during the **Solar House** project and was subsequently extended in the **Invent a Machine** project as her approach to evaluation shifted toward noticing the complexities of what her students could do and how they could do it and shifted away from an approach that placed emphasis on what was missing from student work.

Although the concept of adequate conduct as described by Varela, Thompson and Rosch (1991) encourages a teacher to consider a broader spectrum of student capabilities in evaluating their work it is not clear that it allows for consideration to be given to the distributed nature of cognition as it occurs in building settings. For instance, when a student does something it often opens up possibilities for another student to do something else. This contribution to the collective cognition of the classroom is not considered in Varela, Thompson and Rosch's (1991) notion of adequate conduct which seems to be wholly focused on the relationship between an organism and its environment. When a student builds something in a classroom, it provides the teacher with an affordance which he/she can subsequently use to enhance his/her engagements with other students and it provides other students with an affordance to generate new action-thought. In other words, a student's action-thought may open up new pathways for adequate conduct for others. These pathways are open, in some sense, to the classroom community as a whole, but are realized in individual action. The point is that there is a collective component to individual cognition as it occurs in a community of building/inventing that does not appear to be recognized in Varela, Thompson and Rosch's notion of adequate conduct. How does one evaluate action-thought as an individual creation when it emerges from a community?

Comments on the ontology and epistemology of understanding

It seems to me that the shape of a process of engagement is intrinsically interwoven with questions involving the epistemological and ontological nature of a setting. One might say that interacting epistemological and ontological dimensions emerge from a person's acts of bringing forth a world of significance. The nature of the relationship between epistemological and ontological dimensions can have a profound impact on the shape of a person's process for understanding. I suggest that when questions involving our way of being in a setting achieve a coherence with questions involving the nature of knowledge creation in that setting then the shape of a problem can become embodied and enacted (i.e. understood). In other words, a knower's way of being in a world may take on epistemological significance when the knower is fully implicated in a problem setting. Conversely, a knower's epistemological perspective may take on ontological significance under the same conditions. Under these circumstances, a recursive interaction can be identified between ontological and epistemological dimensions and they can be thought of as being a part of a larger whole. Perhaps our understanding of the world, our selves, and the nature of our relationship with the world depends on our capacities to recursively bring forth ontological and epistemological dimensions in action-thought settings.

One way to think about the relationship between the epistemological and ontological components of understanding is to describe them as independent entities. This kind of relationship may be portrayed in a mathematical way by depicting the entities as orthogonal axes. Now imagine that the relationship between epistemological and ontological components of understanding is more properly thought of as being, in some way, co-determining. Visually that requires the orthogonal axes to tilt toward each other and we have included the possibility of a level of interaction between ontological and epistemological components to understanding. Having made this "bend" in our thinking about the nature of the relationship, let us push the metaphor a little further. Now think of the relationship as being represented by a pair of curved axes which intertwine to form a kind of helical structure. This allows us to think of two levels of recursive interaction. First, the curved axes are never orthogonal. They can be said to be interacting in a mathematical sense. Second, the two curved axes can be thought of as forming a larger whole - i.e., an organization. Now that we have, in some sense, a geometry that seems appropriate, let us attempt to put it into motion in order to include in our model the dynamic quality which we know is present in an enactive portrayal of developing understanding. Suppose we do this by imagining a growing helical structure that emerges piece by piece, a strand on one branch emerging after a strand on the other, in much the same way as a DNA constructs itself. This allows us to imagine a reciprocal growth relationship between two intertwined and interacting components (ontology and epistemology). As the growth process proceeds, a larger organization emerges which may assume a myriad of wonderfully dynamic geometrys composed of combinations of interacting plastic "shapes" that we can think of, in a broad metaphorical sense, as understanding. The point I wish to make is that in any portrayal of a process of developing understanding, one must include both ontological and epistemological components and a mechanism by which they can interact.

The shape of our way of engaging a world (World A) determines the shape of the problem (what significance emerges - i.e. what World A looks like to Person A). The problem as it is perceived by Person A (i.e., the epistemology of person A) generates a world of significance (World A). The emergence of World A changes Person A's way of engaging and "being in" (embodied, ontological component) World A. Ultimately, the shift in Person A's way of being in World A contributes to the generation of a new person (Person Â). A new person subsequently perceives a new world (World Â). This process is naturally recursive and contributes to a process of what Varela, Thompson and Rosch (1991) describe as ontological drift. The recursive relationship between the nature of "what" and "how" for a "persons-acting-in-setting" unit of analysis suggests that portrayals of action-thought should attempt to describe this aspect of thinking in science.

Ideas which exist in physical form seem to have a different ontological and epistemological status from those which do not. It is, of course, possible to move back and forth between the specific and the theoretical (Piaget, 1963; Bruner, 1996). Building seems to offer an affordance for action-thought to bring forth understanding in which there is a connection between the ontological and the epistemological domains. When our ideas and thoughts can be brought forth they become like us, they take shape and exist in a domain similar to that occupied by our bodies. The physical idea maintains a plasticity normally ascribed only to virtual ideas and allows us to enter into the idea as much as it enters into us. I will return to this point later in the chapter.

A note on the mutual specification of theory and practice

Both Varela, Thompson and Rosch (1991) and Bruner (1996) describe knowing in doing as a process in which the knower's way of knowing is determined, to a large extent, by the environment with which he/she interacts. Bruner uses the example of the rower's way of rowing being shaped by the oar. I think that Bruner's description leaves out an essential part of the process which he describes as "knowing as doing". If the rower builds the oar (e.g. if the carpenter-rower constructs her own tool for engaging her environment) then the relationship between knower and environment is significantly changed in the sense that it becomes more dynamic. The environment not only contributes to the shaping of the knower's way of knowing (i.e., shaping the knower) but the knower also contributes to the shaping of the environment itself. In other words, knower and environment mutually specify each other in a recursive process of bringing forth significance - significance in re-creating the environment and re-inventing oneself within that environment.

Can a research account be enactivist?

So far I have commented on enactivist ideas as a way of interpreting persons-acting-in-a-setting. The reader will recall that I am also attempting to explore how enactivist ideas can contribute to a research approach that is viable in a classroom setting. The dilemma for the researcher is the fundamental one between representation and enaction. As a researcher I need to be open to the environment that I am attempting to interpret and, in some sense, understand. If perception is a construction then this creates certain problems. What do we mean by research? In some sense one wants to describe, interpret, and, perhaps, explain some phenomenon. The researcher's cognition plays a role in the research process. Can you at the same time be a part of and separate from the domain of interest? An enactivist would answer "no" while a representationalist would reply "yes" to this question.

Varela, Thompson and Rosch in commenting on Piaget's research describe him as "an objectivist theorist who postulates his subject matter, the child, as an enactivist agent, but an enactive agent who evolves inexorably into an objectivist theorist." (Varela, Thompson and Rosch, 1991, p. 176). In describing myself as a researcher over the course of this study, I would say that I have followed a progression similar to that of Piaget's "child". I have taken a body of enacted experience and represented it in language based portrayals/interpretations of action. A research project portrays the fundamental dichotomy between representation and enaction. On one level my actions were governed by a representationalist stance to cognition in the sense that I was the recipient of information from the environment and was engaged in processing it into a research report. At another level, I attempted to interact with and understand the research environments in an embodied and enacted sense. Recognizing that while it was not possible to be completely enactivist in this study, I believe that it was nevertheless important to try. Maturana recognizes the problem and asserts that an observer has no basis on which to make claims about objects or relations as if they existed independently of his/her actions. Furthermore, consensus among a community of observers does not give validity to a distinction that the individuals cannot make independently. Maturana uses the term "objectivity-in-parentheses" (Maturana, 1988, p. 31) to remind us of the pitfalls of representationalism:

> "In the path of objectivity-in-parentheses, existence is constituted with what the observer does, and the observer brings forth the objects that he or she distinguishes with his or her operations of distinction as distinctions of distinctions in language." (Maturana, 1988, p. 31).

There were essentially two ways in which I incorporated an enactivist stance into my research approach. I did not enter my research settings with a predetermined agenda of research materials, questions, and data gathering techniques. Instead, I took the time necessary to allow myself to be "invited into" students' learning environments. With the passage of time, my presence became a part of the normal classroom environment as the teacher and students included me in their activities. In the meantime a world of significance emerged for me. In a sense, one might say that my research actions were perceptually guided in nature.

One consequence of allowing myself to be perceptually guided allowed a second way to emerge in which I could incorporate an enactivist perspective into my research approach. This second way occurred when I learned how to become a co-participant in the activities students were doing, not as an observer but as a person interested in the phenomenon and contributing to its development. This allowed me to participate in a conversation emerging from, embedded in, and focused on, action-thought. That was essentially as far as I was able to go in exploring an enactivist approach to research. Any account or interpretation of the outcomes of a research project inevitably pulls me back into a representationalist stance of objectivity-in-parentheses.

There was a recursive element to my research approach in that I attempted to revisit settings that embodied similar enactivist characteristics but which differed in terms of their contextual attributes over the course of the work. The element of re-visiting is one way in which I tried to maintain an enactivist stance. I think it is a useful approach because it required me to be physically engaged in an action-setting during much of the time that I was interpreting and portraying a previous research experience. Rather than clouding the interpretations which emerged, a concurrent experience in an action-oriented research setting allowed me to bring these ideas into clearer focus as I attempted to think about how they were connected to the engagements I had with students in the research action-context at hand.

Somewhat fortuitously I could also re-engage with certain individuals, notably Dan, over a extended period of his growth and development as he enacted his world of significance. Being able to interact with Dan over a period of nearly four years allowed me to consider some longer term implications for the ideas I was developing in writing this report. I consider this kind of extended research engagement to be enactivist in nature because it recognizes the possibility that some understandings emerge on longer time scales than others and it allows a more meaningful relationship to develop between the researcher and student.

I would not describe my research perspective as one which is either purely enactivist or purely representationalist in nature. In a sense, I have attempted to find a middle ground which allows me to consider my research questions from the "inside out" (enactivist) and from the "outside in" (representationalist). This is a second example of a recursive element in my approach. In the enactivist sense the emergence of the observer is contingent on a recursive component to perceptually guided action.

For further research

A characteristic of the work of the students in the projects I have described is that they considered their work to be unfinished with possibilities as yet unexplored. This is also an intrinsic characteristic of an enactivist perspective to knowing and being. So it is with my research, which has opened up many more pathways than it has closed. Among areas for further exploration that I have brought forth in my world of significance are the following:

1. How do language and discourse enter into meaning making?

> The enactivist position on language and social engagement involves a complex recursion of consensual action within domains of consensual action. While the use of language has provided me with data, I have not problematized the complex individual meaning structures of language. My work has focused directly on meaning-in-action. Many ways of approaching research on the question of how language enters into meaning making can be explored.

2. How are complexity and developing understanding related?

> My research suggests that over time students are able to abstract capabilities of action-thought into generalized competencies or ways of being viable in shifting environments. While I examined action-thought at various levels of complexity there are many more questions that need to be explored e.g., what is complexity for a student or for a teacher in a dynamic evolving classroom setting?

3. How do the processes of embodiment and recursion interact in the development of understanding?

> My research suggests that there is a connection between embodiment and recursion at different levels of abstraction. How they may be related within the enactivist interpretive framework is an open question.

4. How can research accounts be structured and presented so that a reader can be more enactively engaged in bringing forth meaning from the text?

> At one level, the reader is already complicit in bringing forth meaning from text. In this study I have used essentially a narrative approach supported by exemplars of student discourse and work. Ultimately, the reader has access only to my selections. Research is needed in developing ways of representation that involve the reader more directly in developing their own meanings of events and actions.

Many more questions and issues of theoretical interpretation come to mind. Perhaps enactivist thinking has been a part of our way of being for longer than we can ever say. After all, we all know more than we can say.

> You shall possess the good of the earth and
> sun
>   ... there are millions of suns left,
> You shall no longer take things at
>   second or third hand ...
> nor look through the eyes of the dead ...
> nor feed on the spectres in books,
> You shall not look through my eyes either,
>   nor take things from me,
> You shall listen to all sides and
>   filter them from yourself.
>
> *Walt Whitman* (1855).
> *Leaves of Grass.*

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APPENDICES

A. Administration

B. Student work and Comments

C. Selected Interviews and Conversation

APPENDIX A

Administration

University of Alberta
Edmonton

Canada T6G 2G5

Centre for Mathematics, Science, and
Technology Education
Department of Secondary Education
Faculty of Education

Office: 835 Education South, Telephone (403) 492-0195
Mailing Address: 341 Education South
Fax: (403) 492-9402 Email: SE04@MTS.UCS.UALBERTA.CA

March 26, 1993

Research project on science investigation

This project involves student pairs in a largely self-directed set of investigations with materials developed at UBC for a period of about one hour. No specific science content knowledge is required to perform the investigations and there is no hazard involved. The students will be supervised at all times. The investigative sequence will be followed by about one hour of group discussion and interview with the students. All material will be referred back to the students for comment and none will be used without permission.

The investigation will be conducted by Dr. Heidi Kass, Professor of Science Education and Research Design, and A. Leo MacDonald, research assistant, CMASTE.

Permission is hereby given for

Name ____________________

Address ____________________

____

to participate in the above science investigation project at the University of Alberta on March 29, 1993. Permission is also given to videotape and record the session on the understanding that these are to be used only for research and educational purposes.

____________________ Student

____________________ Parent

____________________ Date

COOPERATIVE ACTIVITIES PROGRAM: RESEARCH APPLICATION FORM

Field Experiences
Faculty of Education
University of Alberta T6G 2G5

833 Education South
492-3661 Fax: 492-0236

---

1. **Instructions**

a) This application form is to be used for research projects which constitute a major undertaking leading to a Master's thesis or a Ph.D. dissertation, and studies of similar magnitude, or lesser research projects which involve participation of human subjects.

b) All proposed research projects involving human participants must be reviewed by the ethics committee established in each department, to ensure that ethical guidelines are followed in the conduct of the study. Once clearance is granted, a statement to this effect, signed by the chairperson of the ethics committee, must accompany this research application.

2. **Organization to be Involved**

Edmonton Public School District ☒ County of Strathcona ☐ N.A.I.T. ☐
Edmonton Catholic School District ☐ St. Albert Protestant/Separate School District ☐

3. **Requester** (University staff member) Date Feb. 23, 1994.

Name (include title) Dr. Heidi Kass Faculty Education
Position Professor of Science Education Department Secondary Education
Address Dept. of Secondary Ed., U. of A. Telephone 492 - 5415
Is this request being made on behalf of a graduate student ☒, undergraduate student? ☐
If so, indicate: Leo MacDonald (Name) 492 - 3760 (Phone Number)
Department of Secondary Education, U. of A. (Campus or Home Address) T6G [illegible] 2G5 (Postal Code)

4. **Description of Research Project** - include title, objectives, procedure, evaluation techniques, ethical considerations, etc.

Project SENSE (Student Enaction in Science Experiences)

The purposes of this study are:

(a) to explore the way student understandings develop in classroom scientific activities and
(b) to develop and refine research approaches to the study of the ways students develop meaning in scientific activities.

...2

4. **Description of Activity/Research Project** (continued):

We will observe students as they engage in science activities, individually or in small groups, which are designed either by the classroom teacher or by us in collaboration with the classroom teacher. We will use a number of observation methods to record classroom discourse and student action including the use of video and audio-tape stations. Transcripts of the video and audio-taped sessions will be shared with the teacher as a point of departure for conversations about our interpretations. Written materials produced by students may be collected when appropriate.

We will then select individual students who display a wide range of investigative behaviors (including students who display both high and low engagement in activities) and invite them to describe moments from an investigative sequence which they consider important for their developing understanding as they view themselves on video.

The study is qualitative. We will construct portrayals of the patterns of talk and action shown by students as they work through various activities. These portrayals will have a "second-order" orientation in that the phenomenon of our research interest (the ways students go about doing a task and the meanings these ways hold for them) is embedded within the phenomenon of attention (e.g. accomplishing an investigative activity).

Parental consent will be obtained according to University of Alberta ethics requirements. Parents and students will be told that the project is intended to add to our understanding and will in no way will affect their achievement or grades. Consent to use written material will be explicitly obtained for each item requested. The students will be advised that any interaction with us is voluntary and that they are free to decline to participate at any time. We feel that our presence and interaction with students in this classroom will enhance the quality of their learning experiences in science as well as contributing to our understanding of this process.

This is the first component of a study which will continue in the fall of 1994.

5. **Anticipated value to the school(s) or school district(s) involved:**

We will collaborate with the teacher in designing activities relevant to the science curriculum. Our interactions with students will help them to develop awareness of their personal ways of making sense during science activities. This may have implications for program design and teacher professional development.

6. **Suggested personnel, school and times:**

We plan to work with Ms.   and the students of her grade nine science class at   Junior High School. We would be present in this classroom on the average of two to three times per week for a period of approximately eight weeks beginning in March, 1994.

7. **Anticipated project completion date (including final report):**

This component of our research project will be completed by April 30, 1994. A report of the results will be prepared in 1994-1995. The data are foundational to L.MacDonald's Ph.D dissertation(1996).

For office use only:

Approved by ____________________, Field Experiences. Date ____________________

Approved by ____________________, School District. Date ____________________

Subject to the following conditions:

a) A report of the results of the findings of this project is to be forwarded to the cooperating school(s). YES ☐ NO ☐

b) A research report on this project is to be forwarded to the school system's central office. YES ☐ NO ☐

DEPARTMENT OF SECONDARY EDUCATION
Application for Departmental Ethics Review

Instructions: Submit one copy of this application and five copies of your proposal done on the Faculty of Education Ethics Review, Description of Project and Procedures for Observing Ethical Guidelines form to the Department's Research Ethics Review Coordinator

Date: Feb. 23, 1994.

Requester(s)

Dr. Heidi Kass (Name) Staff X *Ph.D. Student ___ *M.Ed. Student ___

Leo MacDonald (Name) Staff ___ *Ph.D. Student X *M.Ed. Student ___

*Advisor's Name: Dr. Heidi Kass

Title of Project: Project SENSE (Student Enaction in Science Experience)

Description of Project:

This description should be done on the form attached.

FOR OFFICE USE ONLY

Review Panel:

Name

LB LARRY BEAUCHAMP
J. Kirman
J.O. J. Oster
J. CARSON

Signature of Panel Chairperson: L. Beauchamp

Date: Feb 23/94

X This application conforms with the provisions contained in the University Policy Related to Ethics in Human Research document.

___ This application does not conform with the provisions contained in the University Policy Related to Ethics in Human Research document.

Ethics Review Document (Solar House Project)

Project Title: Processes of Student Understanding in Self-Directed Scientific Understanding

Applicants: Leo MacDonald & Heidi Kass

Department: Secondary Education

Date: 18 February 1994

Statement of Research Problem and Methods

The purposes of this study are:

(a) to explore the way student understandings develop in classroom scientific activities,
(b) to explore and refine research approaches to the study of the ways students develop meaning in scientific activities, and
(c) to develop questions and ideas leading to more extensive investigations in this area.

The qualitative methods used will combine observation of students engaged in scientific activities with interviews about instances designed to reveal the meanings these experiences hold for them. The project will involve two main components: (1) a school science classroom characterized by a high degree of hands-on student activity and (2) a clinical component which involves individual students in open-ended self-directed science investigations.

In the school component students will be observed as they engage in science activities ,individually or in small groups, which are designed either by the classroom teacher or by the researchers in collaboration with the classroom teacher. We will explore a number of observation methods to record classroom discourse and action including the use of video and audio-tape stations. Transcripts of the video and audio-taped sessions will be made and used to explore methods of portraying the ways students developed meaning during these sessions.

In the clinical component a small number of students will be invited to participate at the University of Alberta in scientific investigative activities designed by the researchers. The participants will be observed and video-taped during these sessions. We will explore and refine methods to encourage students to reveal the ways they develop meaning in self-directed investigation by inviting them to talk about (1) their actions as they observe themselves on video-tape and (2) alternative approaches demonstrated by a researcher for an investigative sequence. This aspect of the clinical component will also be video-taped, transcribed and used to explore methods of portraying the ways students developed meaning during these sessions.

Who are the participants and how will they be involved in your research?

Participants will be students from a grade nine science classroom at a local school. They will work on activities that fit the Alberta science curriculum. The researchers will be present in the students' classroom on the average of two to three times per week for a period of approximately eight weeks beginning in March, 1994. Data will be gathered by video and audio-tape and by written notes made by the researchers. Written materials produced by students may be collected when appropriate (this is not a major component of the study but we leave it open as an option).

A small number of students will be invited to participate in the clinical component where they will be engaged in open-ended self-directed scientific investigation tasks. The extent of involvement will depend on the interest shown by the individual student and could range from one session to several sessions.

How will the nature and purpose of the research be explained to participants?

The research problem and methods and the nature of the students involvement outlined above will be verbally presented to the students in their school science classroom. At that time the students will receive a written summary of the research project and a consent form to be signed by parents. Formal consent to begin the project will only be assumed after these documents have been read and signed by all parents and returned to the researchers. The researchers will at all times during the project encourage and answer questions about the nature and purpose of the research.

How will informed consent of participants be obtained?

Parents of the students will receive written information about the purpose of the research, and a consent form (see attached) prior to the commencement of the project. The written information will include a description of the research problem and methods and the nature of the participants' involvement in the project. The written information will inform parents and students of their rights to further information, withdrawal at any time, and personal confidentiality. The same information will be duplicated on the consent form. Permission to video-tape classroom and clinical sessions will be obtained from the school administration and the teacher involved. The parents of the students in this class and the students themselves will be asked on the consent form to indicate whether or not they are willing to be video-taped during the classroom and clinical sessions. Consent to duplicate and use any written material produced by students will be explicitly obtained for each item so requested from the student.

Are children, captive or dependent populations used? If so, detail how consent will be obtained.

Yes. The students are from a grade nine science classroom at a local school. The parents and the students will be explicitly told that the project is intended to add to the researchers understanding and in no way will affect the achievement or grades of the students. Written consent will be obtained from the parents and the students prior to observing and recording sessions on video-tape. The parents or classroom teacher will have the right to request that individual participants withdraw from the research if the research is thought to be interfering with their school work in any way.

How will provision be made for exercising the right to opt out at any time?

The parents and students will be informed, verbally and through the information they receive with the consent form, that they may withdraw from the research project at any time by informing a researcher or their classroom teacher that they wish to do so. Because the research is not dependent on the participation of a certain number of students nor upon any individual student, there will be no pressure on any student for continued participation. Similarly, a student who is uncomfortable working with another member of the project will have the option of withdrawing from the project at any time. In the event that permission to video-tape a specific student is denied then activities involving that student will not be video-taped.

How will confidentiality and anonymity be maintained?

All materials gathered during the research which could identify individual students will be kept confidential by the two researchers involved. General summary descriptions of students will be shared with the teacher where appropriate. However, individual student actions and discourse will not be identified. In published reports students will have pseudonyms and transcripts of sessions will be edited to remove information which might serve to identify a student, the classroom, the teacher, and the school.

Is deception and/or risk involved in the project? If so, how will the interests of the subjects be protected?

No deception or risk is involved in the project. All science activities will be supervised by the classroom teacher and/or the researchers who are also certified teachers.

Are there any other procedures relevant to your observation of the ethical guidelines that are not described above?

No.

University of Alberta
Edmonton
Canada T6G 2G5

Department of Secondary Education
Faculty of Education
341 Education South, Telephone (403) 492-3674
Fax: (403) 492-9402 Email: SE04@MTS.UCS.UALBERTA.CA

March , 1994.

Dear Parent or Guardian,

We are interested in studying the ways students learn during their classroom science activities and self-directed scientific investigations. Ms. 's grade nine science class at Junior High School provides an exciting activity based setting suitable for our research. The results of our study will inform teachers, teacher educators, and other researchers in science education about the nature of student learning in science.

During the study your son or daughter will be observed along with other students as they work on their normal science activities. We will be present in the classroom on the average of two to three times per week for a period of approximately eight weeks beginning in March, 1994. On selected occasions your son or daughter will be invited to comment on his/her learning experiences and the meanings that they hold for him/her. We are planning to video-tape and audio-tape activities and conversations involving your son or daughter in order to ensure the accuracy and authenticity of the information we gather. Occasionally we may find it useful to copy a sample of your son's or daughter's written work. We will ask for your son's or daughter's permission on each such occasion. Video/audio tapes involving your son or daughter and/or copies of their work will be used only for the development and interpretation of our research.

Our presence in the classroom will not affect your son's or daughter's grades or achievement in any way. All students understand that their participation in any portion of this project is voluntary and that they are under no obligation to interact with us if they do not wish to do so at any time. Any information which could identify your son or daughter to anyone will be kept confidential at all times. Video and/or audio-tapes involving your son or daughter will be used for research purposes only. We would be pleased to answer any questions that you may have at any point during our project. Please contact us by phone (403) 492-5415 or Fax (403) 492-9402. Thank you in advance for giving consent for your son or daughter to participate in our study.

Yours sincerely,

Heidi Kass

Leo MacDonald
PhD student

Dr. Heidi Kass
Professor of science education

....

Research Participation Consent Form for Parents or Guardians March , 1994.

Please circle YES or NO below and complete the appropriate blank spaces). Detach at the dotted line above and return by Friday.

YES I hereby give permission for my son/daughter (insert name)____________________ to participate in the Science Activity study with Heidi Kass and Leo MacDonald of the University of Alberta during March-April, 1994. The investigators may video-tape and audio-tape my son/daughter during the research period.

NO I do not wish to have my son/daughter (insert name)____________________ included in the research project.

Signature ____________________________ Date ____________________

University of Alberta
Edmonton
Canada T6G 2G5

[illegible]
Faculty of Education
341 Education South, Telephone (403) 492-3674
Fax: (403) 492-9402 Email: SE04@MTS.UCS.UALBERTA.CA

December , 1994.

Dear Parent or Guardian,

We are interested in studying the ways students learn during their classroom science activities and self-directed scientific investigations. Ms. science class at Junior High School provides an exciting activity based setting suitable for our research. The results of our study will inform teachers, teacher educators, and other researchers in science education about the nature of student learning in science.

During the study your son or daughter will be observed along with other students as they work on their normal science activities. We will be present in the classroom nearly every day for a two to three week period on three separate occasions during the school year beginning in December 1994. On selected occasions your son or daughter will be invited to comment on his/her learning experiences and the meanings that they hold for him/her. We are planning to video-tape and audio-tape activities and conversations involving your son or daughter in order to ensure the accuracy and authenticity of the information we gather. Occasionally we may find it useful to copy of a sample of your son's or daughter's written work. We will ask for your son's or daughter's permission on each such occasion. Video/audio tapes involving your son or daughter and/or copies of their work will be used only for the development and interpretation of our research.

Our presence in the classroom will not affect your son's or daughter's grades or achievement in any way. All students understand that their participation in any portion of this project is voluntary and that they are under no obligation to interact with us if they do not wish to do so at any time. Any information which could identify your son or daughter to anyone will be kept confidential at all times. Video and/or audio-tapes involving your son or daughter will be used for research purposes only. We would be pleased to answer any questions that you may have at any point during our project. Please contact us by phone (403) **492-5415** or Fax (403) **492-9402**. Thank you in advance for giving consent for your son or daughter to participate in our study.

Yours sincerely,

Leo MacDonald
Leo MacDonald
PhD student

Heidi Kass
Dr. Heidi Kass
Professor of science education

……………………………………………………………………………………

Research Participation Consent Form for Parents or Guardians December , 1994.

Please circle **YES** or **NO** below and complete the appropriate blank spaces).
Detach at the dotted line above and return by Friday.

YES I hereby give permission for my son/daughter (insert name)________________________ to participate in the Science Activity study with Heidi Kass and Leo MacDonald of the University of Alberta during December, 1994 - April, 1995. The investigators may video-tape and audio-tape my son/daughter during the research period.

NO I do not wish to have my son/daughter (insert name)________________________ included in the research project.

Signature ________________________ **Date** ________________________

Project SENSE (Student Enaction in Science Experiences)

The purposes of this study are:

(a) to explore the way student understandings develop in classroom scientific activities and
(b) to develop and refine research approaches to the study of the ways students develop meaning in scientific activities.

We will observe students as they engage in science activities, individually or in small groups, which are designed either by the classroom teacher or by us in collaboration with the classroom teacher. We will use a number of observation methods to record classroom discourse and student action including the use of video and audio-tape stations. Transcripts of the video and audio-taped sessions will be shared with the teacher as a point of departure for conversations about our interpretations. Written materials produced by students may be collected when appropriate.

We will then select individual students who display a wide range of investigative behaviors (including students who display both high and low engagement in activities) and invite them to describe moments from an investigative sequence which they consider important for their developing understanding as they view themselves on video.

The study is qualitative. We will construct portrayals of the patterns of talk and action shown by students as they work through various activities. These portrayals will have a "second-order" orientation in that the phenomenon of our research interest (the ways students go about doing a task and the meanings these ways hold for them) is embedded within the phenomenon of attention (e.g. accomplishing an investigative activity).

Parental consent will be obtained according to University of Alberta ethics requirements. Parents and students will be told that the project is intended to add to our understanding and will in no way will affect their achievement or grades. Consent to use written material will be explicitly obtained for each item requested. The students will be advised that any interaction with us is voluntary and that they are free to decline to participate at any time. We feel that our presence and interaction with students in this classroom will enhance the quality of their learning experiences in science as well as contributing to our understanding of this process.

This is the second component of a study. The first component began in March, 1994 and the second component will continue in the 1994-95 academic year.

We will collaborate with the teacher in designing activities relevant to the science curriculum. Our interactions with students will help them to develop awareness of their personal ways of making sense during science activities. This may have implications for program design and teacher professional development.

We plan to work with Ms. and the students of her Jr. High science class at Junior High School. We would be present in this classroom nearly every day for a two to three week period on three separate occasions during the school year beginning in December 1994.

This component of our research project will be completed by April 30, 1995. A report of the results will be prepared in 1995-1996. The data are foundational to L.MacDonald's Ph.D dissertation(1997).

EDMONTON PUBLIC SCHOOLS

December 7, 1994

(File #033.94)

BOARD OF TRUSTEES
Dick Mather
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Usha Procinsky

Mr. Randy Wimmer, Director
Practicum Placement
Division of Field Services
University of Alberta
Edmonton, Alberta
T6G 2G5

Dear Mr. Wimmer:

Re: Research Request: Student Enaction in Science Experiences: (Kass)

The above research request has been approved on a permissive basis following examination by our department. The approval is subject to the following conditions.

1. Teachers and student participation in the study to be voluntary;
2. Students are free to withdraw at any time;
3. Parental permission will be sought for students to participate in the study;
4. The results of the study will be provided to the teacher;
5. Anonymity of the students and the confidentiality of information obtained is assured;
6. The video tape cannot be used for commercial purposes; and
7. The researcher provides a copy of the results to this office.

Leo MacDonald should now contact , principal, School to obtain approval and to make the necessary arrangements for conducting the study.

The district would appreciate receiving a copy of the study results as they become available. (PLEASE QUOTE FILE # ABOVE)

Yours sincerely,

Simon van der Valk
Supervisor Monitoring and
Student Information

SVV/MG/mh

cc: , principal, School
Leo MacDonald

EDMONTON PUBLIC SCHOOLS

December 19, 1994

(File #031.94)

Mr. Randy Wimmer, Director
Practicum Placement
Division of Field Services
University of Alberta
Edmonton, Alberta
T6G 2G5

BOARD OF TRUSTEES
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Angus McBeath
EXECUTIVE ASSISTANT
[illegible]
ASSOCIATE SUPERINTENDENTS
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Dear Mr. Wimmer:

Re: Research Request: Project SENSE-2 (Student Enaction in Science Experiences): (Kass)

The above research request has been approved on a permissive basis following examination by our department. The approval is subject to the following conditions.

1. Teachers and student participation in the study to be voluntary;
2. Students are free to withdraw at any time;
3. Parental permission will be sought for students to participate in the study;
4. The results of the study will be provided to the teacher;
5. Anonymity of the students and the confidentiality of information obtained is assured;
6. The video tape cannot be used for commercial purposes, and
7. The researcher provides a copy of the results to this office.

Leo MacDonald should now contact , principal, School to obtain approval and to make the necessary arrangements for conducting the study.

The district would appreciate receiving a copy of the study results as they become available. **(PLEASE QUOTE FILE # ABOVE)**

Yours sincerely,

for
Simon van der Valk
Supervisor Monitoring and
Student Information

SVV/MG/mh

cc: , principal, School
, teacher, School
Leo MacDonald

CENTRE FOR EDUCATION
One Kingsway
Edmonton, Alberta T5H 4G9
Tel: (403) 429-8000 Fax: (403) 429-8318 24 Hour Infoline (403) 429-8560

University of Alberta
Edmonton
Canada T6G 2G5

Faculty of Education
Undergraduate Student Services
Student Records/Field Experiences
1-107 Education Centre North, Telephone (403) 492-3659
Fax (403) 492-7533

COOPERATIVE ACTIVITIES PROGRAM

PROJECT APPLICATION
(Research)

ORGANIZATION TO BE INVOLVED (Please Check)

[✓ Edmonton Public School District]
County of Strathcona
N.A.I.T.
Edmonton Catholic School District
St Albert Protestant/Separate School District

APPLICANT (University Staff Member)

Date DEC. 13/94

Name HEIDI KASS / LEO MACDONALD

Faculty EDUCATION

Position PROFESSOR / PHD STUDENT

Department SECONDARY EDUCATION

Campus Address 350 EDUCATION SOUTH

Telephone 492-5415

Is this request being made on behalf of a graduate student? [✓ YES] NO
undergraduate student? YES NO

If yes, indicate:

LEO MACDONALD
Student's Name

492-1730
Phone Number

SECONDARY EDUCATION
Campus or Home Address

T6G 2G5
Postal Code

INSTRUCTIONS

- This application form is to be used for research projects leading to a Master's thesis or a PhD dissertation, and studies of similar magnitude, or lesser research projects which involve participation of human subjects.
- All proposed research projects involving human participants must be reviewed by the ethics committee established in each department, to ensure that ethical guidelines are followed in the conduct of the study. Once clearance is granted, a statement to this effect, signed by the chairperson of the ethics committee, must accompany this research application.

. . . 2

University of Alberta
Edmonton
Canada T6G 2G5

Department of Secondary Education
Faculty of Education
341 Education South, Telephone (403) 492-3674
UALBERTA.CA

Project SENSE-2 (Student Enaction in Science Experiences)

Description of Research Project: The purposes of this study are:

(a) to explore the way student understandings develop in classroom scientific activities and
(b) to develop and refine research approaches to the study of the ways students develop meaning in scientific activities.

Procedure: We will observe students as they engage in science activities, individually or in small groups, which are designed either by the classroom teacher or by us in collaboration with the classroom teacher. We will use a number of observation methods to record classroom discourse and student action including the use of video and audio-tape. Transcripts of the video and audio-taped sessions will be shared with the teacher as a point of departure for conversations about our interpretations. Written materials produced by students may be collected when appropriate. We will also observe selected students as they work on out-of-class science activities such as science olympics. We will then select individual students who display a wide range of investigative behaviors (including students who display both high and low engagement in activities) and invite them to describe moments from an investigative sequence which they consider important for their developing understanding as they view themselves on video.

Method: The study is qualitative. We will construct portrayals of the patterns of talk and action shown by students as they work through various activities. These portrayals will have a "second-order" orientation in that the phenomenon of our research interest (the ways students go about doing a task and the meanings these ways hold for them) is embedded within the phenomenon of attention (e.g. accomplishing an investigative activity).

Ethical considerations: Parental consent will be obtained according to University of Alberta ethics requirements. Parents and students will be told that the project is intended to add to our understanding and will in no way affect their achievement or grades. Consent to use written material will be explicitly obtained for each item requested. The students will be advised that any interaction with us is voluntary and that they are free to decline to participate at any time.

Value to school district involved: We will collaborate with the teachers in designing activities relevant to the science curriculum. Our interactions with students will help them to develop awareness of their personal ways of making sense during science activities. This may have implications for program design and teacher professional development.

Suggested personnel, school and times: We plan to work with Mr.   and the students of his science classes at   High School. We will be present in his classroom nearly every day for two to three week periods on two or three separate occasions beginning in January, 1995. We will also work with the students and teachers who are engaged in out-of-class science activities during this time.

Anticipated project timeline and completion date of final report: This component of our research project will be completed by April 30, 1995. A report of the results will be prepared in 1995-1996. The data are foundational to L.MacDonald's Ph.D dissertation(1997).

DEPARTMENT OF SECONDARY EDUCATION
Application for Departmental Ethics Review

Instructions: Submit one copy of this application and five copies of your proposal done on the Faculty of Education Ethics Review, Description of Project and Procedures for Observing Ethical Guidelines form to the Department's Research Ethics Review Coordinator

Date: Dec 8/94

Requester(s)

LEO MACDONALD (Name) Staff ___ *Ph.D. Student ✓ *M.Ed. Student ___

HEIDI KASS (Name) Staff ✓ *Ph.D. Student ___ *M.Ed. Student ___

*Advisor's Name: HEIDI KASS

Title of Project: PROCESSES OF STUDENT UNDERSTANDING IN SELF-DIRECTED SCIENTIFIC UNDERSTANDING

Description of Project:

This description should be done on the form attached.

FOR OFFICE USE ONLY

Review Panel:

Name

Tom Kieren

L. Beauchamp

W. Samiroden

S. Sigurdson

Signature of Panel Chairperson: Thomas E. Kieren

Date: 12 Dec. /94

✓ This application conforms with the provisions contained in the University Policy Related to Ethics in Human Research document.

___ This application does not conform with the provisions contained in the University Policy Related to Ethics in Human Research document.

Ethics Review Document (Mousetrap Car Project)

Project Title: Processes of Student Understanding in Self-Directed Scientific Understanding

Applicants: Leo MacDonald & Heidi Kass

Department: Secondary Education

Date: 7 December 1994

Statement of Research Problem and Methods

The purposes of this study are:

(a) to explore the way student understandings develop in classroom scientific activities,
(b) to explore and refine research approaches to the study of the ways students develop meaning in scientific activities, and
(c) to develop questions and ideas leading to more extensive investigations in this area.

The qualitative methods used will combine observation of students engaged in scientific activities with interviews about instances designed to reveal the meanings these experiences hold for them. The project will involve two main components: (1) a school science classroom characterized by a high degree of hands-on student activity and (2) an out-of-class component which involves individual students in open-ended self-directed science investigations such as science olympics.

In the school component students will be observed as they engage in science activities, individually or in small groups, which are designed either by the classroom teacher or by the researchers in collaboration with the classroom teacher. We will explore a number of observation methods to record classroom discourse and action including the use of video and audio-tape stations. Transcripts of the video and audio-taped sessions will be made and used to explore methods of portraying the ways students developed meaning during these sessions.

In the out-of-class component a small number of students will be observed and video-taped during the planning and development of their science olympics tasks. We will explore methods to encourage students to reveal the ways they develop meaning in their self-directed investigations by inviting them to talk about their actions as they observe themselves on video-tape. This discourse will also be video-taped, transcribed and used to explore methods of portraying the ways students develop collaborative strategies and individual meanings during these sessions.

Who are the participants and how will they be involved in your research?

Participants will be students from elementary, junior high and senior high classrooms in local schools. They will work on activities that fit the Alberta science curriculum. The researchers will be present in the classroom nearly every day for a two to three week period on separate occasions during the school year beginning in December 1994. Data will be gathered by video and audio-tape and by written notes made by the researchers. Written materials produced by students may be collected when appropriate (this is not a major component of the study but we leave it open as an option).

A small number of students will be invited to participate in the out-of-class components where they are engaged in open-ended self-directed scientific investigation tasks. The extent of involvement will depend on the interest shown by the individual student and could range from one session to several sessions.

How will the nature and purpose of the research be explained to participants?

The research problem and methods and the nature of the students involvement outlined above will be verbally presented to the students in their school science classroom. At that time the students will receive a written summary of the research project and a consent form to be signed by parents. Formal consent to begin the project will only be assumed after these documents have been read and signed by all parents and returned to the researchers. The researchers will at all times during the project encourage and answer questions about the nature and purpose of the research.

How will informed consent of participants be obtained?

Parents of the students will receive written information about the purpose of the research, and a consent form (see attached) prior to the commencement of the project. The written information will include a description of the research problem and methods and the nature of the participants' involvement in the project. The written information will inform parents and students of their rights to further information, withdrawal at any time, and personal confidentiality. The same information will be duplicated on the consent form. Permission to video-tape classroom and clinical sessions will be obtained from the school administration and the teacher involved. The parents of the students and the students themselves will be asked on the consent form to indicate whether or not they are willing to be video-taped during the classroom and out-of-class sessions. Consent to duplicate and use any written material produced by students will be explicitly obtained for each item so requested from the student.

Are children, captive or dependent populations used? If so, detail how consent will be obtained.

Yes. The students are from science classrooms at local schools. The parents and the students will be explicitly told that the project is intended to add to the researchers understanding and in no way will affect the achievement or grades of the students. Written consent will be obtained from the parents and the students prior to observing and recording sessions on video-tape. The parents or classroom teacher will have the right to request that individual participants withdraw from the research if the research is thought to be interfering with their school work in any way.

How will provision be made for exercising the right to opt out at any time?

The parents and students will be informed, verbally and through the information they receive with the consent form, that they may withdraw from the research project at any time by informing a researcher or their classroom teacher that they wish to do so. Because the research is not dependent on the participation of a certain number of students nor upon any individual student, there will be no pressure on any student for continued participation. Similarly, a student who is uncomfortable working with a member of the project will have the option of withdrawing from the project at any time. In the event that permission to video-tape a specific student is denied the activities involving that student will not be video-taped.

How will confidentiality and anonymity be maintained?

All materials gathered during the research which could identify individual students will be kept confidential by the two researchers involved. General summary descriptions of students will be shared with the teacher where appropriate. However, individual student actions and discourse will not be identified. In published reports students will have pseudonyms and transcripts of sessions will be edited to remove information which might serve to identify a student, the classroom, the teacher, and the school.

Is deception and/or risk involved in the project? If so, how will the interests of the subjects be protected?

No deception or risk is involved in the project. All science activities will be supervised by the classroom teacher and/or the researchers who are also certified teachers.

Are there any other procedures relevant to your observation of the ethical guidelines that are not described above?

No.

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Department of Secondary Education
Faculty of Education
341 Education South. Telephone (403) 492-3674
Fax: (403) 492-9402 Email: SE04@MTS.UCS.UALBERTA.CA

January , 1995.

Dear Parent or Guardian,

We are interested in studying the ways students learn during their classroom science activities and self-directed scientific investigations such as science olympics. Mr. . . . . science classes at . High School provide an exciting activity based setting suitable for our research. The results of our study will inform teachers, teacher educators, and other researchers in science education about the nature of student learning in science.

During the study your son or daughter will be observed along with other students as they work on their normal science activities. We will be present in the classroom nearly every day for a two to three week period on three separate occasions during the school year beginning in January, 1995. On selected occasions your son or daughter will be invited to comment on his/her learning experiences and the meanings that they hold for him/her. We are planning to video-tape and audio-tape activities and conversations involving your son or daughter in order to ensure the accuracy and authenticity of the information we gather. Occasionally we may find it useful to copy of a sample of your son's or daughter's written work. We will ask for your son's or daughter's permission on each such occasion. Video/audio tapes involving your son or daughter and/or copies of their work will be used only for the development and interpretation of our research.

Our presence in the classroom will not affect your son's or daughter's grades or achievement in any way. All students understand that their participation in any portion of this project is voluntary and that they are under no obligation to interact with us if they do not wish to do so at any time. Any information which could identify your son or daughter to anyone will be kept confidential at all times. Video and/or audio-tapes involving your son or daughter will be used for research purposes only. We would be pleased to answer any questions that you may have at any point during our project. Please contact us by phone (403) **492-5415** or Fax (403) **492-9402**. Thank you in advance for giving consent for your son or daughter to participate in our study.

Yours sincerely,

LeoMacDonald
Leo MacDonald
PhD student

Heidi Kass
Dr. Heidi Kass
Professor of science education

……

Research Participation Consent Form for Parents or Guardians January , 1995.

Please circle **YES** or NO below and complete the appropriate blank spaces).
Detach at the dotted line above and return by Friday.

YES I hereby give permission for my son/daughter (**insert name**)________________ to participate in the Science Activity study with Heidi Kass and Leo MacDonald of the University of Alberta during January - April, 1995. The investigators may video-tape and audio-tape my son/daughter during the research period.

NO I do not wish to have my son/daughter (**insert name**)________________ included in the research project.

Signature ________________________ **Date** ________________

APPENDIX B

Student Work and Comments

Paper Towel

You have in front of you three kinds of paper towel: pink, white and brown.

This is what you have to find out: -

Which kind of paper will hold the most water?

You can use any of the things in front of you. Choose whatever you need to answer the question.

Make a clear record of the results so that someone else can understand what you have found out.

Pink: ~~2.25~~ g 2.4g
Brown: 2.1g 2.2g
White: ~~2.45~~g 2.6g
— masses of various sheets of paper towel

Paper Towel

You have in front of you three kinds of paper towel: pink, white and brown.

~~water beaker: 76.4g~~

This is what you have to find out: -

489.8 g — mass of dry pan

Which kind of paper will hold the most water?

~~[illegible]~~ White because it's the heaviest paper

You can use any of the things in front of you. Choose whatever you need to answer the question.

1 Liter in plate

Make a clear record of the results so that someone else can understand what you have found out.

	Test 1 Amount of water (g)	Test 2 Amount of water (g)	Test 3 Amount of water (g)
Pink	228.5g - 76.4 - (2.1×4) = 143.7g	570.1g - 489.8 - (2.4×4) = 70.7g	590.9 = 489.8 - (2.4×4) = 81.59
Brown	227.5 -	554.9 - 489.8 - (2.2×4) = 56.2g	590.9 - 489.8 - (2.2×4) = 82.3
White		~~555.8 - 489.8 -~~ 555.7 - 489.8 - (2.6×4) = 55.5	570.4 - 489.8 - (2.6×4) = 70.2

2
2.6
4
10.4

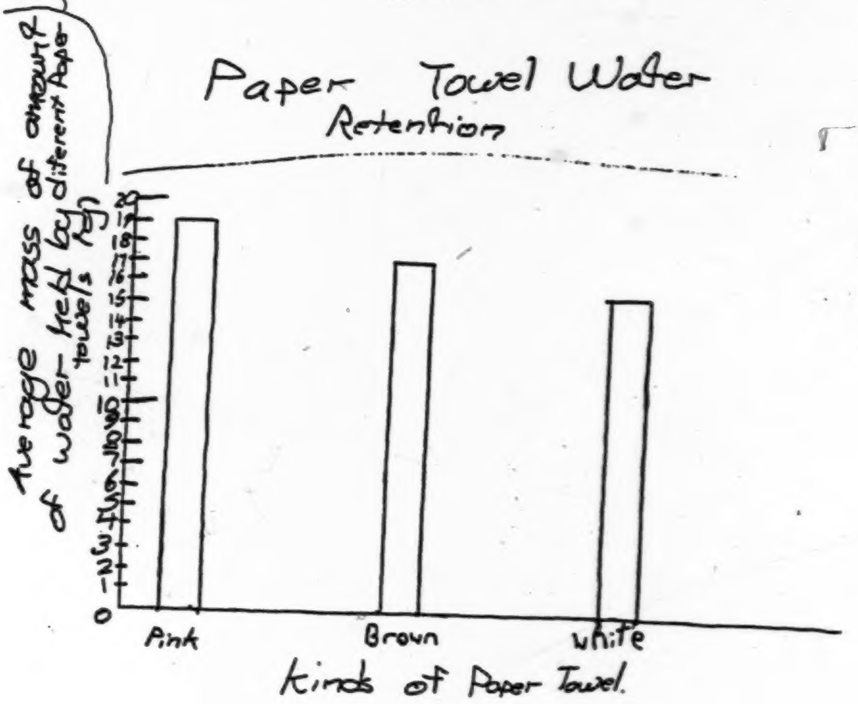
Find averages of same sheets and divide by four to find average individual sheet water retention.

You may write or draw to answer the question.

	~~Average in (g)~~
~~Pink~~	~~76.145 g~~
~~Brown~~	~~69.25 g~~
~~White~~	~~62.95 g~~

Sheets	Average retention per sheet (g)
Pink	19.03625g
Brown	17.3125g
White	15.7125g

Paper Towel Water Retention



SAVE THE ICE CUBE

PURPOSE: To build a container which keeps an ice cube from melting by reducing the flow of heat into the container.

BACKGROUND INFORMATION: You know heat flows from where there is a lot of it to where there is less of it, i.e. from a region of high temperature to a region of low temperature.
CONDUCTIVITY occurs when heat flows through material. The best conductors are metals and the worst is air. How can you reduce heat loss by conductivity?
CONVECTION occurs when heat flows via a heated fluid expanding and rising, and cooler air flowing in to replace it. For convection to occur there must be a fluid and circulation. How can you reduce heat loss by convection?
RADIATION occurs when energy travels in waves, either through matter or through space. Both absorption and emission of radiation occurs most in non-shiny, black surfaces and least in shiny, silver surfaces. How can you reduce the loss of heat by radiation?

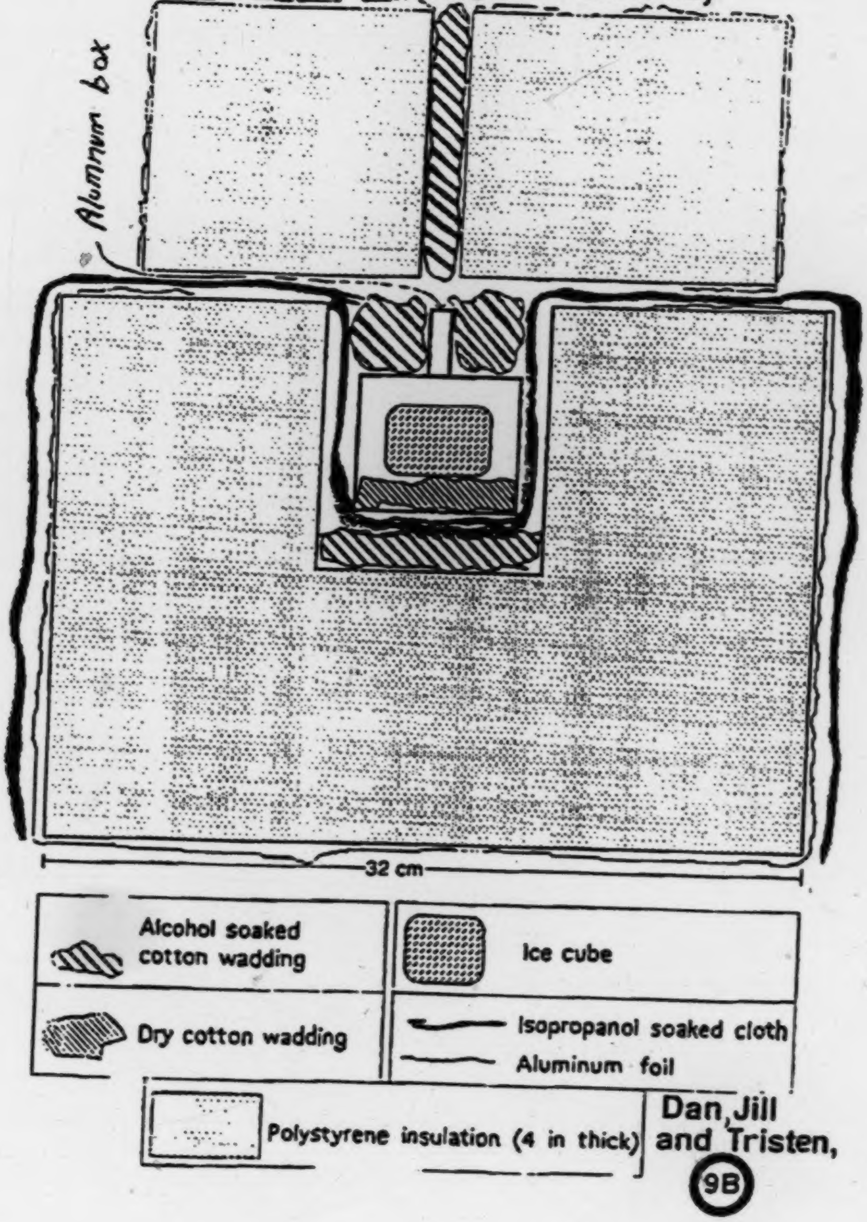
MATERIALS: From school - shredded newspaper, cotton batting, Styrofoam pellets, wood shavings, sand, sawdust, aluminum foil, glue, scissors, tape
From home - a container, any other insulation

PROCEDURE:
1. Plan your container (diagram, notes). Show your teacher.
2. Construct your container.
3. TO TEST YOUR CONTAINER: Get an ice cube, weigh it, and put it into your container. After several hours open your container and weigh the remaining ice cube.
4. Make improvements to your container and test again.

OBSERVATIONS:

time	mass (g) of ice cube		
	trial 1	trial 2	trial 3
start at _______			
end at ______			
total time(min)			
% mass of ice lost			

ANALYSIS
1. Write paragraph(s) describing how you created your most effective container. Be sure to tell how you reduced heat loss by a.) conduction b.) convection c.) radiation
2. Draw and label a "cut-away" diagram of your most effective container.



Ice Cube Refridgerator Cutaway

Aluminum box
32 cm
Alcohol soaked cotton wadding
Ice cube
Dry cotton wadding
Isopropanol soaked cloth
Aluminum foil
Polystyrene insulation (4 in thick)

Dan, Jill
and Tristen,
(9B)

The Ice Cube Box

by

Jill, Dan, and Tristen

ial # 1

The exterior of ar 'ice cube box' was constructed
1 four inch thick, high density, polystyrene, or
afoam. The purpose for using this was that it is a
rial which has high thermal resistance. It was
cted that the styrafoam would not conduct heat
the outside environment.

The actual Ice cube was placed on a piece of
and that was surrounded by a small aluminum box, which
been chilled prior to use. The purpose of the chilling
at cold air converts heat at a lesser degree than
air. The top of the aluminum box had a small
that's purpose was to secure a rubber tube
ed to a vacuum pump. As a final step, the air
the aluminum box was pumped out using this
d because 'dead air space' is a poor conductor
heat.

The starting weight of the ice cube was 17g
ily. The final weight after being in the box for
hours was 0 g.

al #2

The design of the box was not altered greatly.
concept concerning the vacuum pump was
rded because there were many problems
ounding it. For example, although the aluminum
iner was extremely 'leak-proof', one minute
fection would have caused a considerable amount
r to rush back inside.
The ice cube, this time weighing 21g, was on a
of chilled plastic and the surrounding area was
with ice water-soaked cotton
A towel soaked with rubbing alchohol was placed
d the aluminum box. The reason for doing
was that the alchohol would evaporate. This change
rate occurring made it possible, by energy taken from
cube itself and its surroundings (the container,
otton, plastic, and the polystyrene) to cool the entire
he box was placed in a window so that venting
remove that energy which was in the form of vapours.
hole that had been made for the vacuum pump
ntly filled with alchohol-soaked cotton.
After the same amount of time as in Trial #1, the
ng weight was 11.8g, 56% of the beginning weight.

After reviewing the observations of both trials, it
i obvious that Trial #2 was more successful. Yet, ther
s reason not to discard all results from Trial #1
ecause comparibly, the Ice cube used was smaller
an any other group's ice cube by about 2/3.

BUILD A SOLAR HOUSE

PROBLEM: To build a "house" which has maximum solar gain and retention, AND which reduces/prevents heat loss.

BACKGROUND INFORMATION:
Use your textbook to make notes on Passive Solar Heating (p. 158) and Active Solar Heating(p.159)

MATERIALS:
-all materials from Ice Cube experiment, polystyrene, glass

PROCEDURE:
1. Read the Procedure on p. 160 of your text. Brainstorm answers to questions.
2. Diagram a plan for your solar house. Show your teacher.
3. Build a "house" (one room is OK) with features of passive or active solar heating.
4. To test your house:
    a. Position a 200 watt lamp 50 cm away from the front/roof of your house
    b. Take the starting temperature of the air inside your house by inserting a thermometer into the house.
    c. Shine the light on your house for no more than 30 min.
    d. Take the temperature after heating and at intervals until the house is at room temperature.
5. Make improvements to your house and test again.

OBSERVATIONS:

time	temperature(oC) inside solar house trial 1	 trial 2	 trial 3
*			
**			

*before heating **immediately after heating

ANALYSIS:
1. Write paragraph(s) describing how you created your most effective solar house. Be sure to tell how your house:
a.)gained maximum solar energy
b.)retained maximum solar energy
c.)reduced heat loss by conduction, convection, radiation
2. Draw and label a "cut-away" diagram of your most effective solar house.
3.)Graph your data with time on the x axis and temperature on the y axis, using the scale your teacher gives you.

FOCUS QUESTIONS FOR REFLECTION

1. What do you like about your completed project?

2. What strengths about yourselves did you discover or affirm while doing this project?

3. What parts of this project did you find easy? What parts did you find difficult?

4. Did you find anything that was unexpected or surprised you as you worked on this project? If so, please describe it.

5. What limitations did you encounter while doing this project? (Limitations of time, effort, enthusiasm,resources or other limitations)

6. If you were to do the project again, what changes might you make?

7. How well did you meet your own expectations in completing this project?

8. (Class 9B ONLY) Did you have an opportunity to discuss your project with Mr. MacDonald? How did those conversations affect the development of your project?

SELF-EVALUATION

Topic____

1. What do you like about your completed project?

2. What strengths about yourselves did you discover or affirm while doing this project?

3. What limitations did you encounter while doing this project? (Limitations of yourselves: time, effort, enthusiasm or limitations of resources)

4. If you were to do the project again, what changes might you make?

5. How well did you meet your own expectations in completing this project?

6. What do you think your classmates liked about your project? Didn't like?

7. Discuss how your group worked together. On the reverse side, list the members of your group. Assign each one a percentage based on the share of the work on your project they completed. (If all members of a 4-member group shared the work equally, each one would be assigned 25%) When you have reached agreement, please initial beside your name. If you would like assistance with this, please ask.

Solar House Analysis
Dan and Tristin, 9B

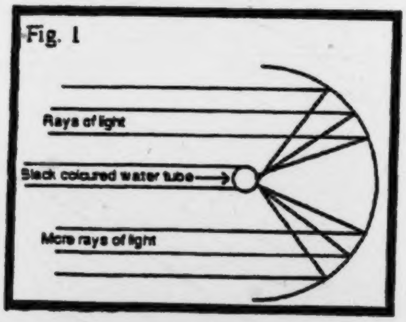
On the Surface ...

We, the designers, decided to go out on a limb and try to use an active solar heating system in our house. We did this by heating water in a plastic tube coated with black construction paper, designed to absorb radiant heat energy from the light and re-emit it so as to heat the water in the tube.

We had planned to use convection as the means of circulating the water through the house (Water in black tube warmed by solar energy, gains energy so particles move faster and faster apart. Density decreases so the warmed water rises and cold water is drawn from the "spent water return hose" by the area of low pressure left when the warmed water rises. At the highest point of elevation that the water would reach, the rubber hose was connected to the copper, at which point, we knew, that heat would begin to be conducted away from the water by the copper pipe, and then emitted into the room in our house. When loosing this energy it would begin to grow dense and circulate down through the 96.55 cm copper coil. To the end of copper pipe was connected the "spent water return hose" through which the cooled water would travel back to the base of the black tube.) Unfortunately, circulation did not occur so we manually poured the water out of the black tube and into the house after the 30 minute heating process had concluded.

Also, we used a curved piece of reflective metal to help focus light rays back on the black tube (see illustration, fig. 1):

Fig. 1

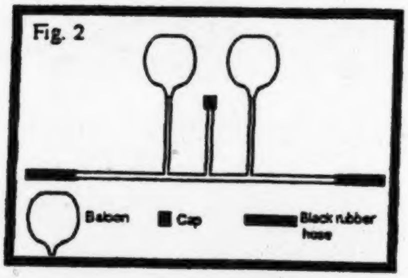


We also covered the outside of the house with black construction paper that could absorb radiant energy and re-emit it as heat on the surface of the house. That probably wasn't a huge factor in the final outcome because the insulation didn't let heat energy out of the house so it probably didn't let any in to start with. But it looked cool anyway, and was better than nothing.

We didn't put any windows in our house because we knew that too much heat could be lost by conduction through the glass and convection through any leaks around it. Also, we were concentrating on getting the active solar system to work.

The last feature visible from the outside was our "glass tree" (see illustration, Fig. 2):

Fig. 2



The function of the balloons was to provide a place for the pressure to go that would result from the subsequent expansion of the water as it was heated by the light. If the pressure had built up to a high, it would be impossible for the water without either popping a hose off of something or the water's density not being able to increase, either way interfering with the operation of our system.

The Insides

The walls of our house were comprised of, from the outside in, the afore mentioned black construction paper, then at least 4 cm of polystyrene (Styrofoam) insulation glued together and then "caulked" with glue to prevent air from circulating from inside to the outside, and loosing heat through that type of convection. The polystyrene has excellent insulation properties that come from the many tiny air pockets, a medium through which heat conducts very poorly, and they're too small to have convection currents forming within them. Also, the plastic itself has no lattice formation among its particles, thus it is a poor conductor of heat.

Next was the fiberglass insulation, which has properties similar to those of the polystyrene for the same reasons (the air pockets formed in-between the strands of fiberglass). Following that was the layer of aluminum foil that despite being a good conductor of heat it will also reflect heat back, and anyway, whatever got past the aluminum foil had to deal with the fiberglass strands. In-between the layers there was no airspace so as to prevent a convection current from forming in there.

Every wall had this same configuration, including the roof, which was built up with extra insulating materials because heat rises, so the point of highest heat loss would be the roof, except that we took care of that with 6 cm of fiberglass strand insulation and 5 cm of polystyrene.

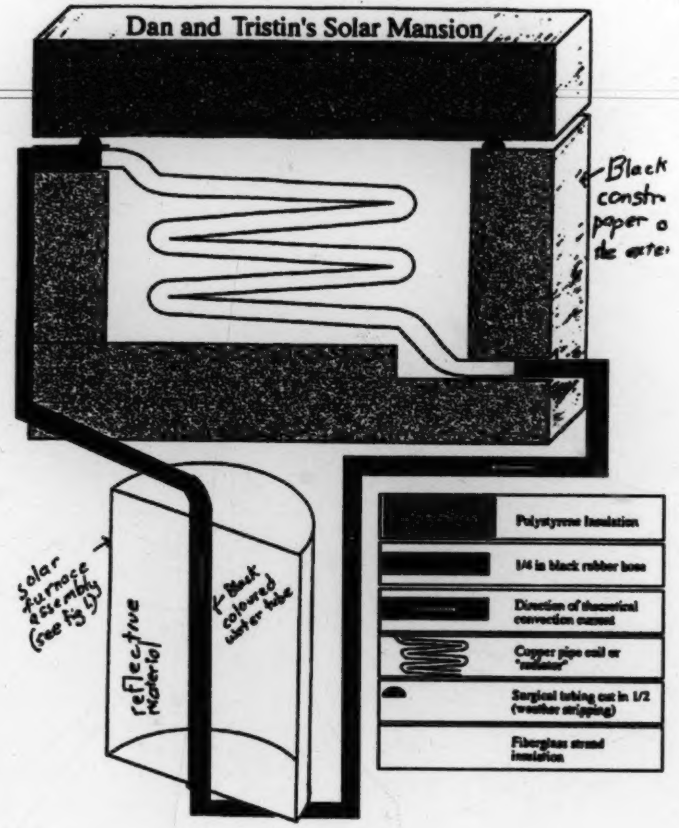
The fiberglass had a dual purpose. Other than just keeping the heat energy inside, it also filled up airspace so that there was less air to heat. Using the logic of specific heat capacity and the formula $H=m\Delta ts$, with less air, m (mass) is lower so less heat energy is required. And although the difference may be less than a whole milligram, air's S.H.C. is very high so even a slightly smaller volume of air would result in a noticeable reduction in the amount of heat required to raise the whole volume's temperature by 1 degree Celsius. Incidentally, the internal volume of the house was 932.8 cm^2. We measured by filling a plastic bag with water inside the house's walls so that the water level was at the point where the walls end and the roof begins, then measured the volume in a graduated cylinder.

Testing it

In the house we had a coil of copper pipe (that we shaped ourselves by heating and then carefully bending it around a 5 inch piece of PVC pipe so as to get it nicely rounded) and because copper is a good conductor of heat (16,000 times better than air) we figured that heat exchange (from the water to the air in our house) would not be a problem, and when we assisted the circulation with gravity the temperature of our house promptly rose from 24 degrees to 38 degrees Celsius. Note, when we unhooked the spent water return hose from the black tube after we had circulated the water through the "heat exchanger" or "radiator" (the copper pipe), it lightly burned my (don's) hand it was still so hot. At that point we blocked the rubber hosing with clothespins to hold what was left of the hot water in the copper pipe so that it could continue to emit heat energy.

Although our house didn't reach the spectacularly high temperature of 79 degrees Celsius, as did Clarence's, it was so well put together that heat loss was only about a degree an hour, so it would conceivably take 13.5 hours to drop back to the starting temperature of 23 degrees Celsius. This gave us 84 square centimeters for the area of our triangle, better than would thought it would be.

We are pleased with the result.


Dan and Tristin's Solar Mansion
←Black constr. paper o the exte
Polystyrene Insulation
1/4 in black rubber hose
Direction of theoretical convection current
Copper pipe coil or "radiator"
Surgical tubing cut in 1/2 (weather stripping)
Fiberglass strand insulation
solar furnace assembly (see fig 5) →
reflective material
← Black coloured water tube

Solar House Project
Response to Focus Questions

Dan, 9B

1. From when we were given the assignment, I knew that I wanted to go for active solar heating (involves the circulation of a liquid) because it was unique and would require a lot of thought, something with which I have no trouble. This is one thing I liked about the project. Another thing was writing up the analysis, I was dreading it but when I got down to it, it seemed to flow so effortlessly. Perhaps the unit testing being out of the way helped because I wasn't really sure whether I had a good grasp of the theories or facts, but I guess I did! This helped me be more confident when writing up the analysis.

2. I confirmed that I like doing detailed work, in respect to both the analysis and actual house, as well as putting a lot of thought into things. This may of been a problem because the first test of the house was the official test, so as far as I was concerned, it was all or nothing. While it didn't perform as well when heating up, it retained heat so efficiently that it more than compensated. From this I learned that waiting patiently for all the data to be in, instead of getting me mad at the initial results, would be a good trait to adopt if I were to pursue a career as a scientist.

But I think that after having recently discovered that my forte is thought when on a tight schedule, perhaps I would make a good theoretical physicist.

3. I found all of the project easy to deal with except the waiting from the switch on the 200 watt lamp to the last temperature measurement at 300 minutes. The concepts were easy to work into the design, but I'll admit, I must have missed something about convection because the water didn't circulate. But I don't need to talk about that here.

4. Two things: that explanation for why the water didn't circulate on the principals of convection still eludes me. Second of all that it retained heat so well even though past the 300 minute mark it is extrapolation, I believe it to be accurate. Besides, at about the 450 minute mark I cracked it open at home and a warm breeze rose out of it for a second. According to the graph it would have been approximately 29.5 degrees in there at the time.

5. Ah, limitations. There were many. Obviously, the magnitude of what I would of liked to do would probably require a sabbatical from school (I wish) to complete, time wise. Given the time to test my ideas out, it might have turned out better still if I'd found the convection malfunction and corrected it with a pump, or tried orienting the parts differently to see if gravity was affecting it.

Also, I had work from all other subjects throughout the development, construction, and analysis to take care of, this helped to drain my energy. Last of all, I was without, of all things, glue with which to assemble my house until two nights before the test day. This is my own fault but my consolation is that it still worked out pretty well.

6. I'd add a pump to assist the convection process, perhaps add a second solar furnace to heat more water. You know, have some heating up already while the other filled up with cold water and got started on heating it up. Also, I would lay insulation around the "glass tree" because we may have lost some heat there. And I would install a one way valve on each balloon so that any liquid or vapor that found its way in would not be able to re-enter the system. I wouldn't want it back in the circulation assembly because it would so easily loose heat through the thin rubber membrane of the balloon that it would re-enter the system cold.

7. As stated above, I at first thought that we had struck out, and this deeply frustrated me. But when I found out that our heat loss rate was so low, I couldn't help but rejoice at its success, so much as to dance an embarrassingly silly jig in my kitchen after I examined the data.

8. Most of my conversations with Mr. MacDonald were actually me telling him what Tristen and I were doing, and interpreting his facial expressions as to whether he thought it would work or not. I think that he was helpful in expressing interest and giving me some things to think about while designing and building the solar house. I think I benefited, no, I know I benefited from his presence. His enthusiasm was very encouraging, and if he reads this, thanks Leo!

Dan

Solar House Project

Focus Questions for Reflection

Tristen, 9B

1. What do you like about your completed project?

I liked that in our project we were able to employ many of the scientific theories that we learned in class. I also enjoyed the development phase of the project and its performance overall though I think it could have been modified to perform better.

2. What strengths about yourselves did you discover or affirm while doing this project?

I discovered a lot about my skills in researching and developing a project. I also discovered that I tended to be very good at implementing different scientific theories etc. into my projects.

3. What parts of this project did you find easy? What parts did you find difficult?

The basic idea to use a water circulation system came to us quite quickly., but when it came to the refining of our idea into a more general concept it started to become more complex. The final construction of the house was fairly easy though the school lacked many of the required supplies. Overall the project was fun but still challenging.

4. Did you find anything that was unexpected or surprising to you as you worked on this project? If so, please describe it.

No, not really. The project went fairly smoothly and was without problems once everything came into place.

5. What limitations did you encounter while doing this project? (Limitations of time, effort, enthusiasm, resources or other limitations).

With the exception of limitation in supplies the only other limitation we had was in time. We could have used more time to refine our house and to do a more through (sic) job in its design.

6. If you were to do the project again, what changes might you make?

The next time I did (sic) this project I would redesign the water circulation system. The house held the heat well, it just needed a more advanced system of transferring the solar heat. In a real house a pump would be used but in this case a reservoir on top flowing into the heated pipes then traveling down through the house most likely would work better.

7. How well did you meet your own expectations in completing this project?

I think that the house performed well though I would have liked it to have heated up more. What I am most pleased about is how the house held in the heat. I feel this is were (sic) the project performed the best.

9. (Class 9B ONLY) Did you have an opportunity to discuss your project with Mr. MacDonald? How did those conversations affect the development of your project?

No, I was not able to.

BUILD A SOLAR HOUSE - Jill

PROBLEM: To build a "house" which has a maximum solar gain and retention, AND which reduces/prevents heat loss.

BACKGROUND INFORMATION

Passive Solar Heating:
- lets solar energy in and prevents if from getting out
- not expensive
- easy to maintain

ex. sun shining in windows

Active Solar Heating:
- designed so that as much solar energy is absorbed as possible by a liquid then distributed throughout the building
- ex. solar panels on a roof

MATERIALS:
- blue polystyrene
- plastic magnifying lens
- black construction paper
- mason
- white glue
- tape
- tape
- black rock

PROCEDURE:
- The dimensions of the box are 15x30, 15x15 (on sides)
- The width of the polystyrene is approximately 2.5 cm
- The magnifying lens will be "hinged" on the top and after the final adjustments, the sides will be securely taped down to reduce air circulation. After the heating has taken place, an additional wall will cover the window

OBSERVATIONS:

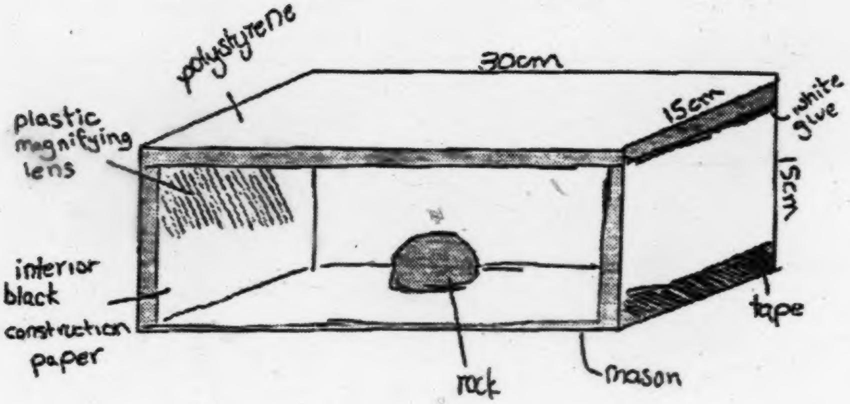
TIME	TEMPERATURE inside the house (oC)
*10:30	23 oC
**11:00	33 oC
***12:30	28 oC
***1:15	28 oC

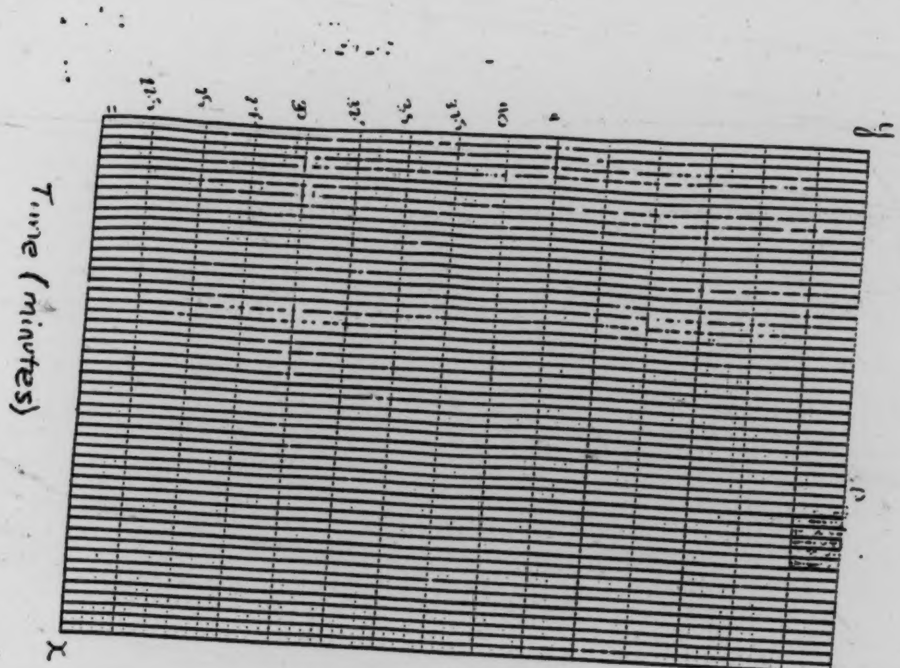
*before heating **imediately after heating *** well after heating

ANALYSIS:

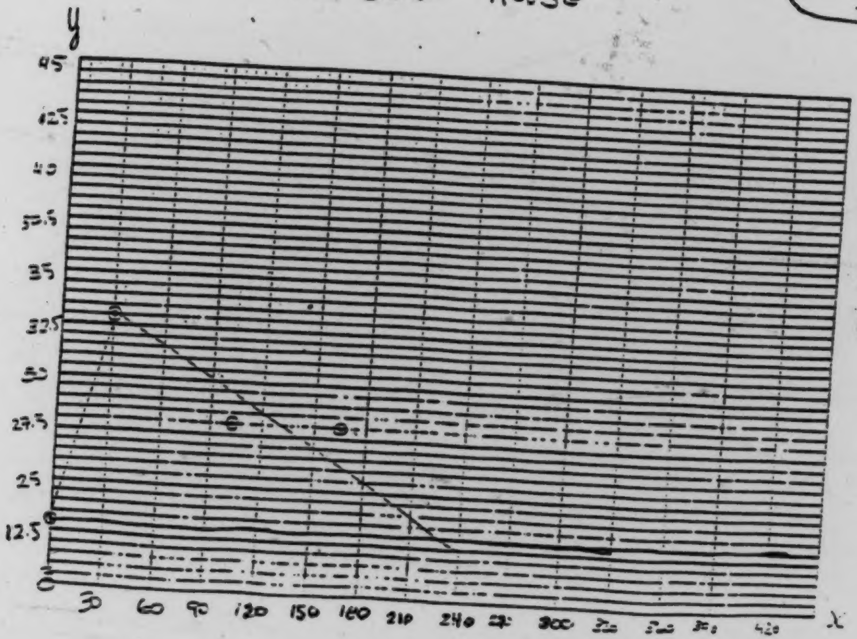
The sides of the house were constructed using polystyrene. One side of it was a tranparent, magnifying piece of plastic. The purpose of the plastic was to allow solar energy in. The focus point of the magnifying lens was directed to a black rock. The rock absorbed the heat and then distributed it equally for a long period of time. The interior of the box was covered with black construction paper because it absorbed the light energy and converted it to heat energy.

Once the initial heating session was finished, the plastic wall was covered with a polystyrene wall and sealed tightly. The polystyrene was used because it does not conduct heat well. All sides of the box except from the plastic side were glued together and the additional wall was taped securely to the box. These actions were taken in order to reduce air circulation.


polystyrene
30cm
plastic magnifying lens
15cm
white glue
15cm
interior black construction paper
tape
rock
mason



The Solar House



Area =
16cm2

FOCUS QUESTIONS FOR REFLECTION

1. My project is very original. I applied many concepts and the results were, in my mind, successful. I was creative in regards to focusing incoming light onto the rock, which would distribute heat equally. I am happy that I thought out and executed my design carefully.

2. I affirmed that I work well by myself because I can use all my ideas and build everything the way I want to without conforming to others thoughts. Also, when I do all the work, it is nice to have all the credit. In the past, I have been stuck with doing all the work in a three or four person group.

3. I found that writing the analysis was fairly easy. I think this was because I assumed my results were because of the use of strategies to gain/retain heat. Therefore, I could reflect on them in my report with more understanding.

I found it difficult to understand the primary goal when heating. I didn't know what I was supposed to achieve (eg. highest temperature and/or retains heat longest).

4. I did not think of a place to insert the thermometer but I found some space to put it. The result could have been a lesser temperature in all respects.

5. We didn't receive many guidelines in regards to if we were on the right track at certain stages in the building of our house.

6. I would insert the thermometer at horizontal angle going upward through the Styrofoam. This would reduce heat loss. I might cover my rock with a black substance somewhat more dull than a Jiffy marker, which is what I used.

7. I was very happy that my solar house not only went up in temperature fairly high, but to find that it remained at a temperature higher than room temperature, which is something many other groups did not accomplish.

8. Throughout this project, I discussed my ideas with Mr. MacDonald. He mainly asked me about my thoughts and impressions, and encouraged me in whatever I was doing at the time, which I appreciate.

Solar House Analysis

- Clarence

1. Background Information:

Passive solar heating: The word "passive" means that the system being used just lets the solar energy in, and tries to keep much heat from escaping.

The sunlight or solar energy goes in through a window or some sort of opening, and then various objects absorb and retain the solar energy. For example, when the light shines in through a window in the downstairs of a passive solar house, the floor absorb the solar energy, and emits it slowly.

Active solar heating: This means that instead of the system not having any moving parts, this system has some substance or another (usually a liquid) absorb the energy, and then pumps it around the house to get the maximum solar energy gain possible.

One other thing about active solar heating is that it usually requires another source of energy to pump the liquid around the house. It would be completely self sufficient if the other source of energy is also solar energy.

2. **Materials:** Styrofoam, polystyrene, charcoal, aluminium foil, multigrade oil.

3. Answers to procedure questions on page 160.

1. Small enough so that there are not too many places where heat loss can occur, and so that there is not too much substance inside so that it will be impossible for the light to heat up, but also big enough so that there is enough room where the solar energy can go.
2. The insulation should contain as much dead air as possible, and it should also be as thick as possible to prevent too much heat loss.
3. They should be evaluated on the scientific principal thought of, the quality of the house, and on how well the houses worked.
4. For my house, I will have a roof that in theory will simulate a movable ceiling. This will be the only movable part on my house so that it will avoid heat loss.
5. I think so. If my house is to heat up a lot, then cool down very fast this will not be fair because when it is hotter inside the house, it will cool down faster until it hits a peak in the cooling down. The insulation will not do a very good job at a very hot temperature because it will begin to conduct the heat. When it gets to a lower temperature, it will stop conducting, and only then would it be fair to evaluate the heating with the insulating.
6. I could put it under a light to simulate the sun.
7. I think that my model will use only passive solar heating because we are not allowed to use any other energy supply in our houses besides the solar energy. This would mean that it would be

---

almost impossible to keep a pump going all the time during the experiment.

8. Only one other question. Will the foam begin to melt if my house gets too hot?

4. **Analysis**:

1. My house gained maximum solar energy by the following ways:
a) I put an oil charcoal in the middle of my house, and surrounded it with more charcoal. I think that the charcoal in the oil absorbed a lot of energy and heated the oil, and that the charcoal around the oil container absorbed a lot of heat and conducted it into the oil. I also think that the oil took a long time to cool down which slowed the cooling of the air inside the container.

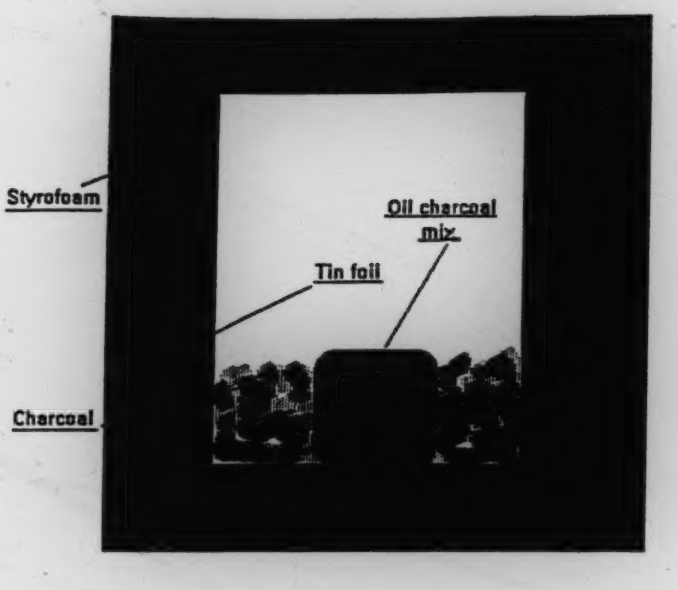
b) The insulation which I used contained a lot of dead air which helped to slow the heat loss. Also, I covered the insides of the room with tin foil. I think that this reflected a lot of the heat which was inside back into the charcoal, of the oil.

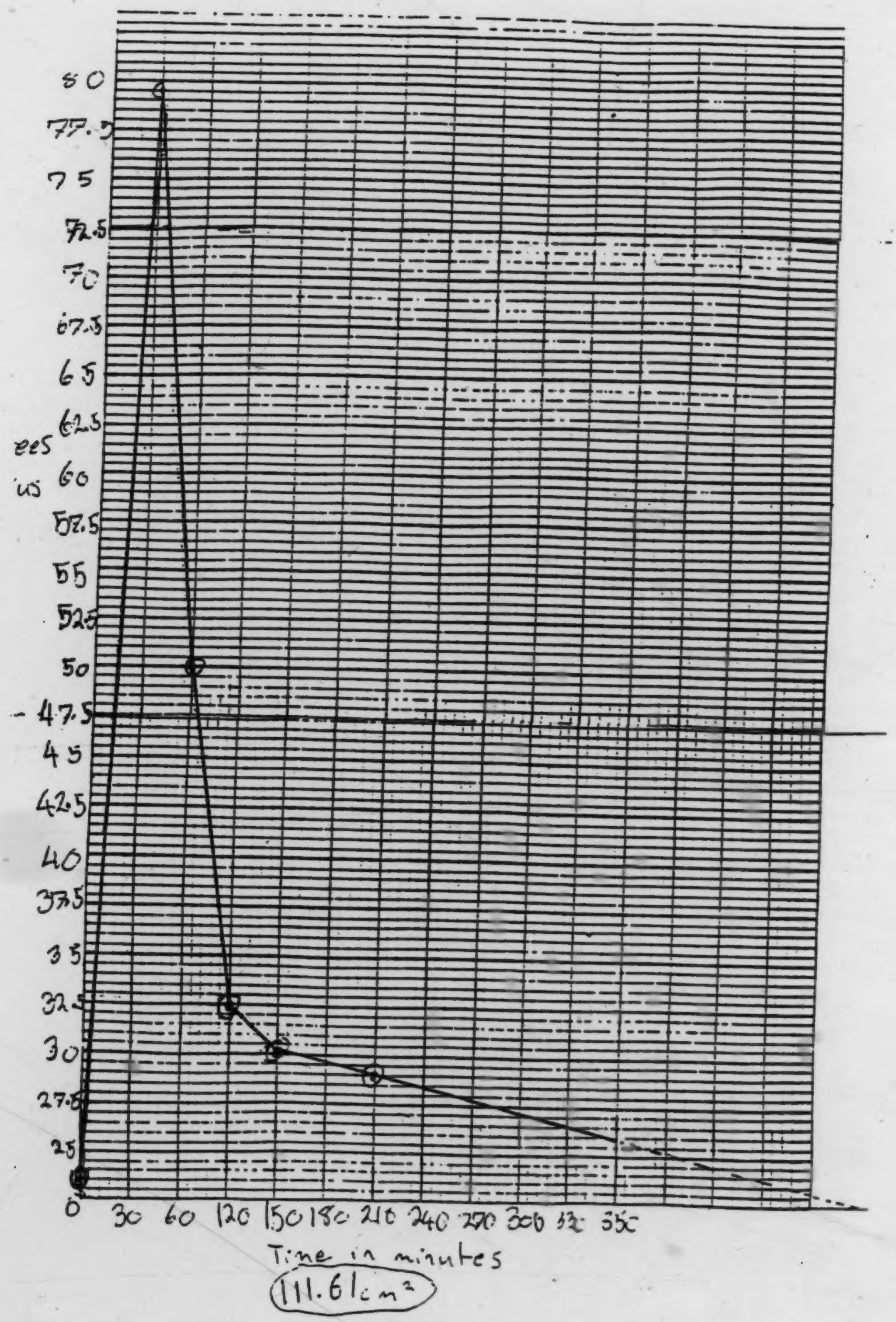
c) Conduction: Since the worst conductor is air, the insulation that I used contained a lot of air. This was the main way to slow conduction.

Convection: I tried to make sure that the container was as air-tight as possible. Also, the oil was in the middle gave a fair amount of energy to the air in the box. This kept the box at uniform temperature. This would reduce convection currents.

Radiation: I reduced heat loss buy putting tin foil on the entire surface of the inside of the box. This helped to reflect all of the radiation.

2. On the next page.


Styrofoam
Oil charcoal mix
Tin foil
Charcoal


80
77.5
75
72.5
70
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62.5
ees
us
60
57.5
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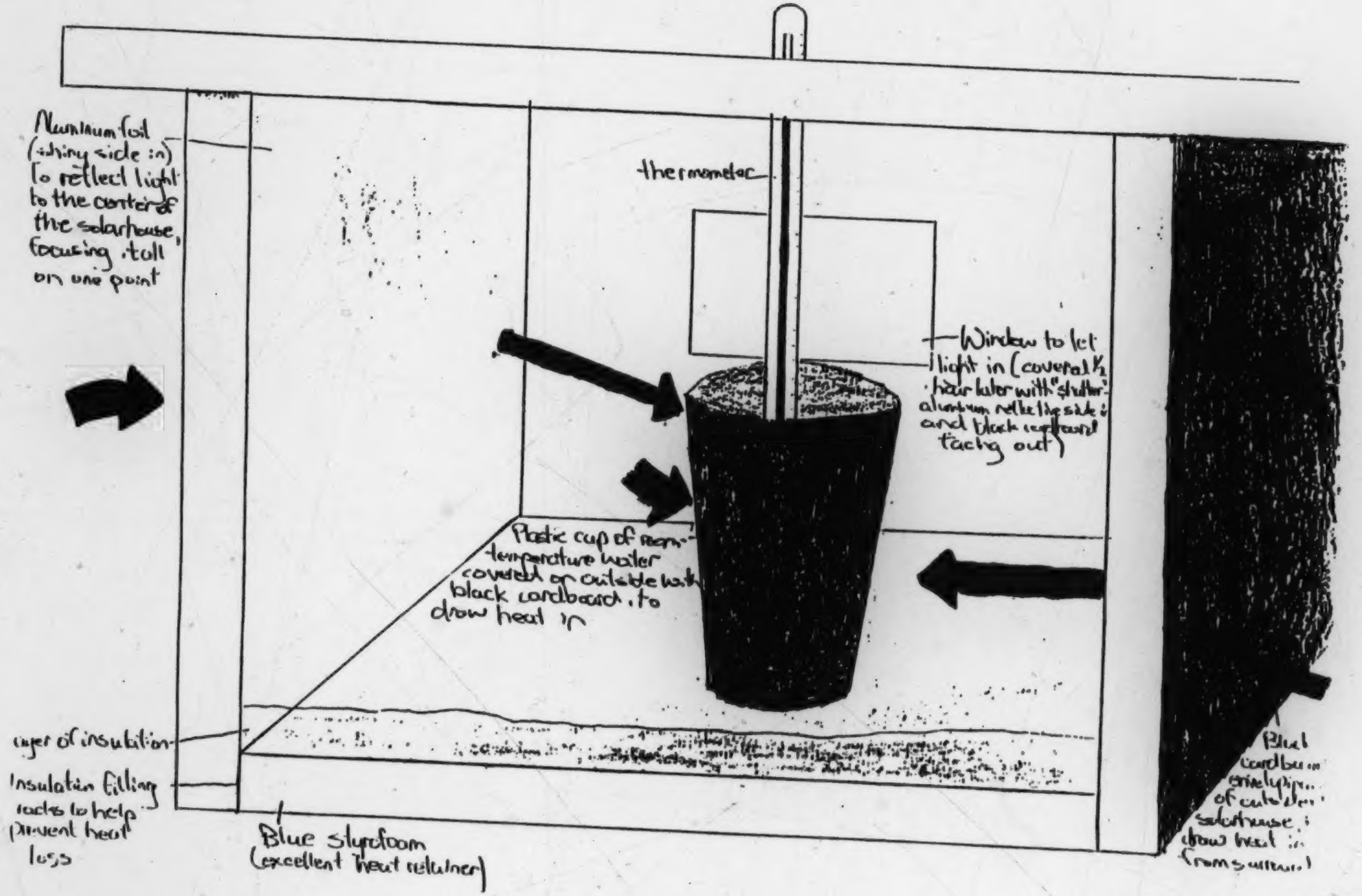
50
47.5
45
42.5
40
37.5
35
32.5
30
27.5
25
0
30
60
120
150
180
210
240
270
300
330
350
Time in minutes
111.61cm²


Aluminum foil (shiny side in) to reflect light to the center of the solarhouse, focusing it all on one point
thermometer
Window to let light in (covered ½ hour later with "shutter": aluminum reflective side in and black cardboard facing out)
Plastic cup of room-temperature water covered on outside with black cardboard, to draw heat in
layer of insulation
Insulation filling racks to help prevent heat loss
Blue styrofoam (excellent heat retainer)
Black cardboard on entire outside of solarhouse to draw heat in from sun

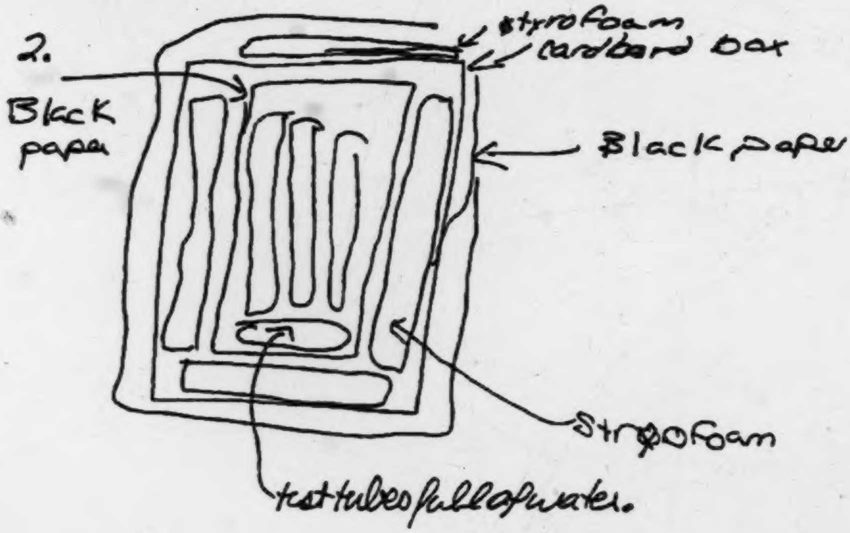
Karla, Helen, and Sarah

1. a) We surrounded the house with black paper which absorbs heat. This idea wasn't very successfule.

b) We lined the box with test tubes filled with water.

c) We lined the house with black paper and the walls were made of styrofoam. and fiberglass.

2.


styrofoam
cardboard box
Black paper
Black paper
Styrofoam
test tubes full of water.

Bernie and Paul's Analysis of their Solar House

In creating our solar home there were several "key issues" that had to be answered but the 2 most important questions were: "How do we get maximum heat gain; how do we keep our heat in" and this is how we answered our question.

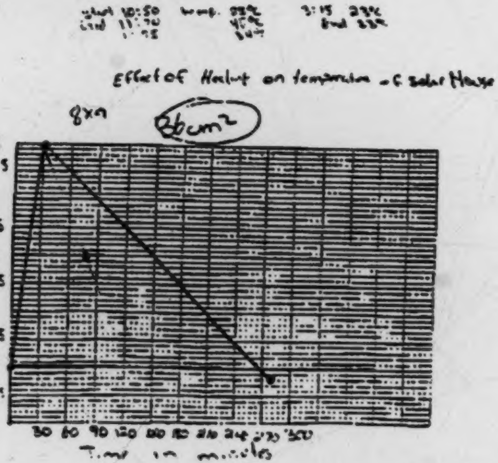
We first needed to know how big our house was going to be. Because we only had 30 minutes to gain (heat) as much energy as possible, we chose to have a small area to heat so that more energy would be gained in a smaller area.

Next we had to decide what materials to use. We already knew that styrofoam was a great insulator and a preventor of heat or cold entering or escaping the box. In addition to the styrofoam, we used fibreglass insulation to decrease any further heat from being lost.

The next decision was how to gain heat and make sure it stays in. We decided that if we could get a beaker with water really warm we would put a cover over the top and just have a little spout to let the warm water vapour out (this would heat up our house too). Now, to heat our water, what we did was put black paper around the beaker, so the suns rays would be absorbed and pass it on to the water to heat it up.

So when we got the water warm, put the tin foil (shinny side facing down on water) over the top of the beaker, got maximum heat in our house, and shut off the light, how could we keep all the heat in and prevent any more light from coming in or escaping. What we did was ingenious. We made our window out of a plastic sports card cover. What this enabled us to do was once we finished heating our house , was put a sports card wrapped in tin foil all around, (shinny side facing out) and place it in the cover. What this did was reflect all the sun's rays away from the house and on the back side as the card (also shinny) all the heat in the house would hit the tin foil and send it back into the house.

To summarize what happened, the sun's ray entered through the plastic window (radiation) and hit the black beaker sitting on the stand in front of the window. The black paper conducted the heat to the water, warming it up. through a little spoute (sic) warm vapours escaped and warmed the tiny living (heated area) space. To keep in heat, blinds were placed in the window and the insulation kept in the heat.



Bernie and Paul

In creating our solar home, there were several "Key Issus" that had to be answered, but the 2 most important questions were: "How do we get maximum heat gain; how do we keep our heat in," and this is how we answered our question.

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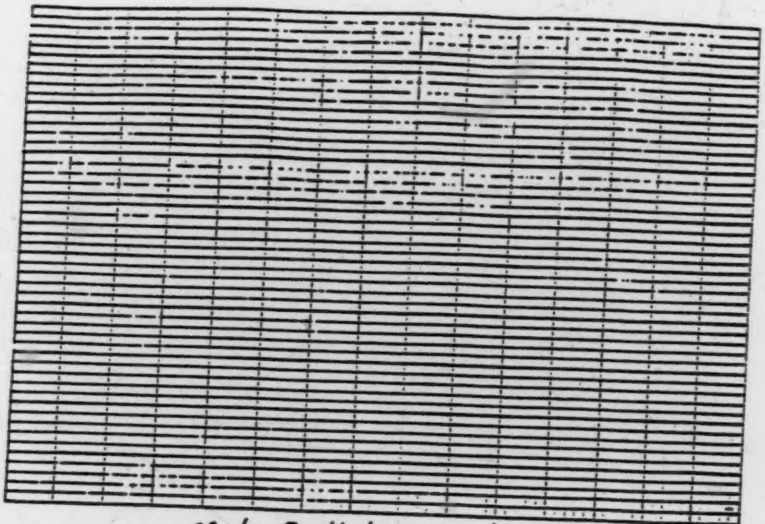
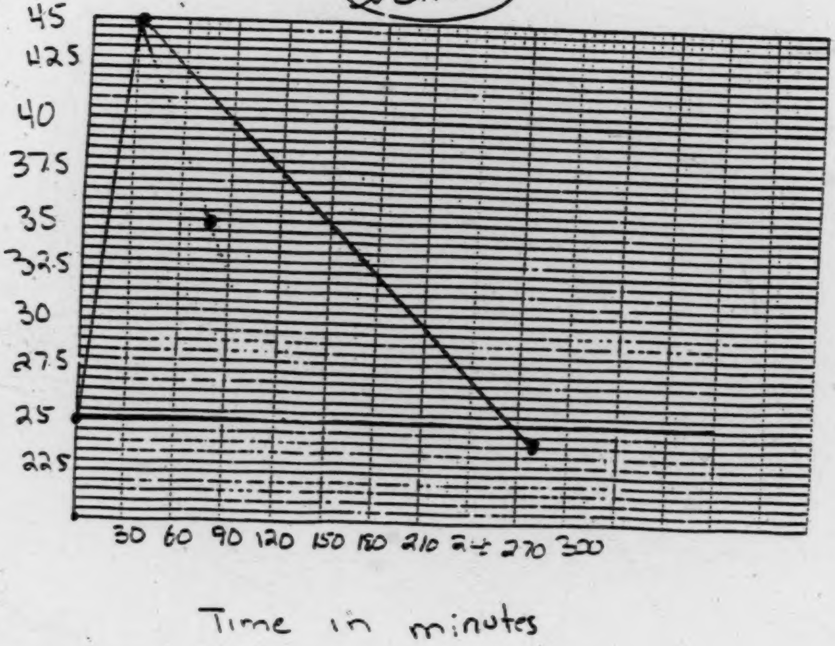
Start 10:50 temp. 25°C 3:15 23°C
End 11:20 45°C End 23°C
1:05 34°C

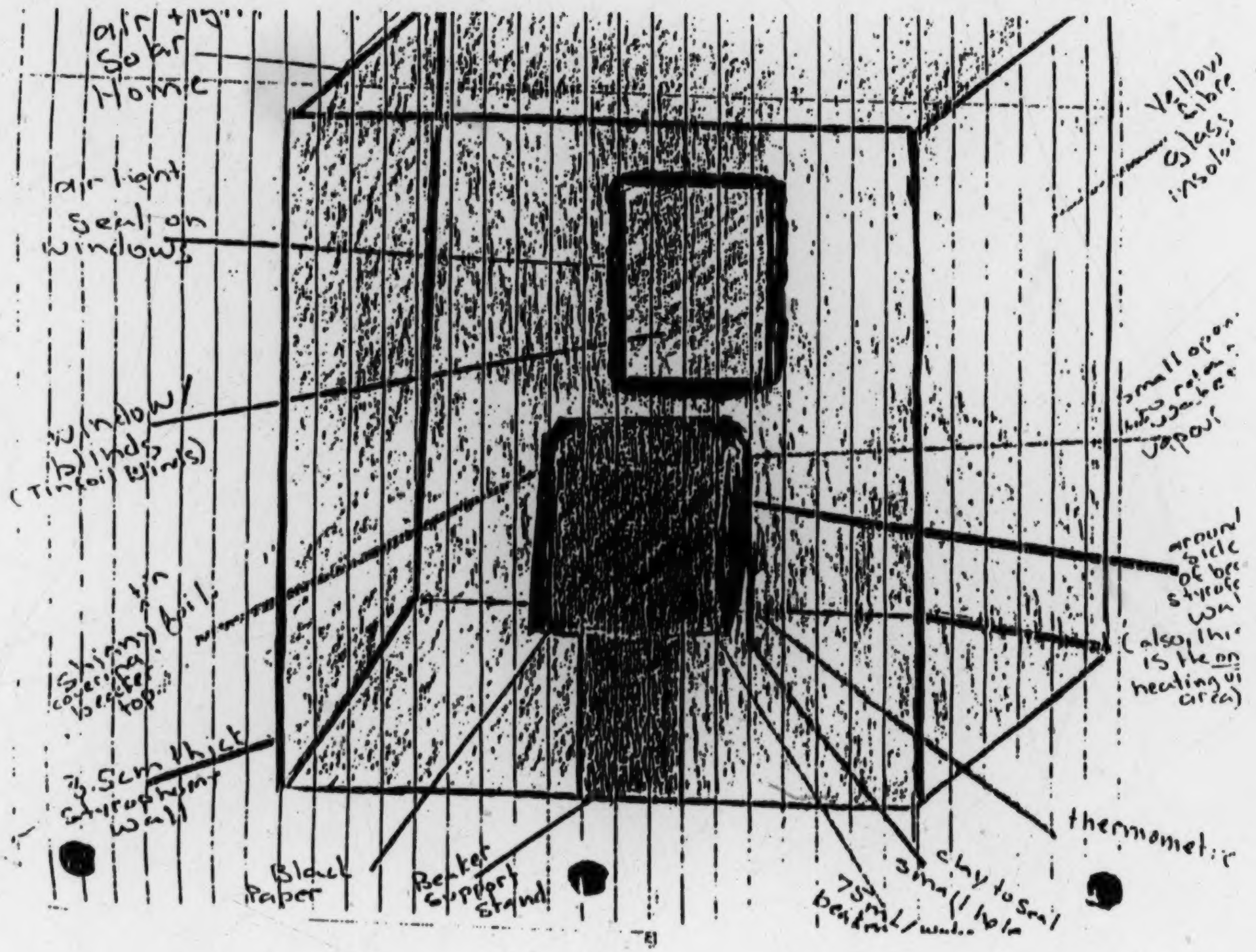


Effect of Heating on temperature of solar House

8x9

36cm²




air tig...
Solar
Home
air tight
seal on
windows
window/
blinds
(Tinfoil blinds)
tin
Shiny foil
covering
beaker
top
3.5cm thick
styrofoam
wall
Black
Paper
Beaker
Support
Stand
75mL
beaker/wate
small hole
clay to seal
thermometer
Yellow
fibre
glass
insola
small open
to release
water
vapour
around
side
of bea
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(also this
is the on
heating u
area)

Solar House Project

Focus Questions for Reflection

1. What do you like about your completed project?

In doing our project, I was really proud in how it turned out. I thought we put a great effort to make the house as successful as it was. I liked the originality of our window + blinds on it. I didn't see anyone else use a sports card cover as a window. I think it made the house a success because a sports card could fit in the slot, + it helped retain heat as we put aluminum around the card. I think that we accomplished more than we wanted too, gaining as much heat as we had, + the amount of time we retained the heat gain.

2. What strengths about yourselves did you discover or affirm while doing this project?

In doing the constructions of the house, I discovered that the learnings (sic) I made in class directly affected the results of our experiment. We learned how to insulate a house and use specific materials to retain maximum heat gain. I also affirmed that working in pairs also helps the house to be the best. This is so, because 2 minds are better than 1, and this way, we could compare 2 factors and research which ways are best to make the house.

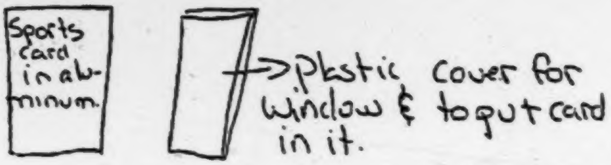
3. What parts of this project did you find easy? What parts did you find difficult?

I found that making the house was very simple. I already had a small box (which I wanted so we only had to heat a small area) and all we had to do was make a roof. We made this with a piece of styrofoam (18 cm x 30 cm).

It was a little difficult to decide what materials we should use and what our house should include. An example of this was whether to have sand on the base of the floor (to gain heat & release heat slowly) or put water in a black beaker and put the thermometer in the beaker (to heat up water & have maximum heat gain and release hot water evaporation. Eventually we settled our disagreements and used the beaker with water.

4. Did you find anything that was unexpected or surprising to you as you worked on this project? If so, please describe it.

There was only 1 real surprise that we stumbled on. When we couldn't cut a glass window out correctly we searched for a new window. We found a hard, plastic sports card cover. What this did, enabled sunlight to enter through the window and when we had to shut off the light, we put a sports card wrapped in aluminum paper (to reflect heat back into the house) shinny side down and placed it through the cover


Sports card in aluminum.
plastic cover for window & to put card in it.

It was surprising because I think the aluminum reflected heat back into the house & the window enabled a great amount of radiant energy to enter the house.

5. What limitations did you encounter while doing this project? (Limitations of time, effort, enthusiasm, resources or other limitations).

I think that we had 2 minor problems. I felt that in-order to get our water boiling in the beaker, we needed more than 30 minutes. I mean we gained 25 C, but a 50 C gain could have been accomplished in about 1 hour. This would have probably kept the heat from being lost so fast. The other problem we encountered was the lack of resources. I mean, we had enough research material, but didn't use them well enough. We didn't look for materials that heat up a great deal. We focused on insulating our home.

6. If you were to do the project again, what changes might you make?

I think that me and Bernie concluded that we needed another material to heat up to get maximum heat gain. This could be done if we used Sam's method, heating up oil. We concluded that it rose about 55 C. If we could add oil and put a seal around the window & base, I think our houses temp. would stay above 25 C for several hours.

7. How well did you meet your own expectations in completing this project?

After having completed our project, I was quite surprised at the results. I was interested in our heat gain because I didn't expect to have a 25 C heat gain. I mean, to travel through a window, a cm wide black beaker, and to heat 25 mm of water is amazing. I never did expect a great gain. I was a little shocked at the rate we lost the heat. I thought that we had a compleate (sic) closed system (air tight) and the materials we used (styrofoam, fibreglass insolation (sic), and blinds on the window) would definately (sic) retain the heat for a long period of time. Unfortunately, we weren't successful enough. I just hope that next time we could fix up our house and explore all our fields of errors.

8. (Class 9B ONLY) Did you have an opportunity to discuss your project with Mr. MacDonald? How did those conversations affect the development of your project?

Yes, we did talk to Mr. MacDonald for a period of time(just a few moments). I think that the conversation affected us in a positive way, as he gave us some valuable feedback. Probably the most effective piece of information he gave Bernie & I was suing a different material for our window. Because the glass didn't fit correctly, we were thinking of using pieces of celentro (sic) wrap. He kind of hinted to us that "plastic" was an effective form of passing radiant energy. He also said that a simple window for our house could be found in any place of a basement or outside on the street. If he hadn't told us about this we would have probably used celentro (sic) wrap and lost all our heat gain immediately. (P.S. He was also very supportive of the material we used).

Solar House Project

Focus Questions for Reflection

Sofia, Katerine, Jasmine

1. We like the fact that our completed project was fairly unique. We were the only group who thought to use sand as absorber of heat. We also liked the design in general of the house. It was well planned out and finished during the set time limits. We also, on the whole, enjoyed constructing our solar house. It was, in fact, very similar to an art project because it was our creation.

2. We found out that all of the members in our group were diligent workers and we all contributed to the building of the house and gave interesting ideas as to what ways we could retain retain the heat most efficiently.

3. Constructing the house was fairly simple but gathering ideas was a great deal more difficult. Although cutting the styrofoam was hard to do because the exact-o-knifes were not long enough.

4. Basically the fact that the house didn't succeed as well as we thought it would was rather surprising. The sand did not retain the heat as long as we had hoped.

5. We found ourselves to be rather limited by the set time-line. We could not work at home because of the number of people in our group and the limited supplys we had at home. It was impossible for us to build a larger, more extravagant and effective house for we did not have such materials as electric fans, wooden structures, mails, etc..

6. To begin with, we'd probably use a thicker styrofoam box, for better insulation and so that there wouldn't be the cracks between the styrofoam that we had on out first house. We'd also probably make it have a lesser are of space inside the box, so it would be easier to heat up. In addition, we would cover the entire box including the inside with black construction paper. On top of the construction paper inside of the house we wouldhave sand. We would also place shreds of newspaper and fibreglass inside the house.

7. The only expectation that was met was that our house would gain a lot of solar energy. Unfortunately the disappointing fact is that the house did not retain this energy for as long as we would of hoped.

8. We found that discussion our project with Mr. MacDonald helped straigten our ideas out in our own minds. He aslo asked us questions that pointed us in the right direction and made us think about ways in which we could improve our project.

GRADE 8 SCIENCE - ENERGY AND MACHINES

Constructing a Mechanical Device

In this activity, students will demonstrate the following technological problem-solving skills:

1. identify the purpose of their mechanical device and list specifications, e.g. to lift a 100 g mass 30 cm
   to carry a 1 kg mass 3 m
   to push/pull a 500 g mass 1 m
2. plan and design a mechanical device that will accomplish a specific task through the application and transfer of energy, e.g. to use a 1.5 v battery to move a 1 kg car
   to use a 1 m ramp at 30o to propel a 500 g cart
   to use a 15 cm elastic to power a 50 g airplane
3. test the design by constructing a simple mechanical device
4. troubleshoot the design by identifying and correcting practical problems, e.g. due to excessive friction
   in the fit/meshing of moving parts
   identify potential hazards
5. evaluate the design

PROBLEM: How can you design and build a machine that:
a.) performs a simple task,
b.) uses at least three of the simple machines you've learned about, and
c.) uses a source of energy other than your own chemical energy?

PROCEDURE:
1. Decide on a simple task you would like a machine to do. Write specific standards for your machine to meet, e.g.
   *how far must it go?
   *how fast/slow must it go?
   *how much of a load must it carry/lift/push/pull?
   *other design possibilities

See examples in Expectation #1 above.
Your machine must meet certain criteria supplied by your teacher, such as having:
   *at least three simple machines (lever, wheel & axle, pulley, ramp, wedge, screw)
   * perform WORK by exerting a force over a distance in the direction of the force
   * use a source of energy other than the chemical energy you supply
2. Decide how your machine will be powered. See examples in Expectation #2 above. For additional examples, see p.94 of your text.
3. Design and build a machine to carry out the task. You may use Lego, Meccano, Construx, Capsella or other construction materials.
4. Test your machine and make improvements. See examples in Expectations #3 above.

5. Present your machine to your classmates. (DUE __________)
Include the following:
    - a demonstration of your machine's operation
    - an explanation of the simple machines in your device
    - a description of how your design changed from start to finish as you were constructing the machine
6. Hand in the following paperwork on your machine:
    - Part 1 - Understanding the Problem (DUE ____________)
    - Part 2 - Developing a Plan (DUE____________________)
    - Part 3 - Carrying Out the Plan (DUE ________________)
    - Part 4 - Evaluating (DUE ___________________________)

EVALUATION
Your project will be evaluated on the following basis:

*Paperwork	/20
*Machine	/20
-Does it meet all criteria?	
*Presentation	/15
*Work habits	/10
-Effort	
-Worked cooperatively	
-Kept on task	
-Respected opinion of others	
-Left work area neat	
TOTAL	/65

SAMPLES OF PAPERWORK

1. UNDERSTANDING THE PROBLEM
    a. What is the purpose or function of your machine?
    b. What specific standards must your machine meet?

2. DEVELOPING A PLAN
    a. What construction materials will you use?
    b. What power source will you use?
    c. What alternatives might you use in case your first idea does not work?
    d. Sketch your machine below.

3. CARRYING OUT THE PLAN
    a. Test your machine. What works well? What doesn't?
    b. What improvements have you made in your machine?
    c. What other improvements do you need to make?

4. EVALUATING
    a. What do you like about your machine?
    b. What would you like to improve on your machine?
    c. If you could start over, what changes would you make in your design AND in your planning process?

The first statement might be completed with,
"the marble was raised 50 cm along the spiral track," or
"the car dragged a load up the ramp," or
"the sugar cube was dropped into the cup."

The second statement might start with,
"Chemical energy was converted into electrical energy in the battery,"
"Mechanical energy of the motor was converted into kinetic energy in the spinning axle,"
"Potential energy of the steel ball was converted into kinetic energy when the ball rolled down the ramp."

Part C - Reflecting on the Process

Write paragraph answers to each of the following questions:

1. What do you like about your completed project?
2. What strengths about yourself or selves did you discover or affirm while doing this project?
3. What parts of this project did you find easy? What parts did you find difficult?
4. Did you find anything that was unexpected or surprising as you worked on this project? If so, please describe it.
5. What limitations did you encounter while doing this project? (e.g. limitations of time, energy, enthusiasm, materials, resources such as books or people and so on)
6. If you could start over, what changes would you make:
   a. in your design ?
   b. in your planning process?
7. How well did you meet your own expectations in doing this project?
8. Did you have an opportunity to discuss your project with Mr. MacDonald? How did those conversations affect the development of your project?
9. If you worked with another person, describe how the two of you shared the tasks of designing and building this machine. What portion of the work was done by each person? Was the division of labour or sharing of responsibility equal?

Student Planning Sheet #1 (Invent a Machine Project)

1. UNDERSTANDING THE PROBLEM
   a. What is the purpose or function of your machine?

   b. What specific standards must your machine meet?

Student Planning Sheet #2 (Invent a Machine Project)

2. DEVELOPING A PLAN
   a. What construction materials will you use?

   b. What power source will you use?

   c. What alternatives might you use in case your first idea does not work?

   d. Sketch your machine below.

GRADE 8 SCIENCE - ENERGY AND MACHINES
Constructing a Mechanical Device
ANALYSIS

Part A - An Overview of your Machine

In the first paragraph, describe the task your machine performed. Was this the task you originally designed your machine to do? How well did your machine function in performing the task? What, if any, were its faults?

In the second paragraph, describe the specifications your machine met. Were these the original specifications you wanted your machine to meet? If your specifications changed, explain how you changed them.

Part B - A Detailed Look at Your Final Machine

1. Use a sheet of graph paper to draw a detailed diagram of the final version of your machine. Use one color for each different simple machine (e.g. red for levers) and linkages (connections such as string, marble, wire). Use a legend to help your readers match the colours to the machines and linkages. If necessary show more than one view. If levers are used, identify the class and use symbols to show the fulcrum ( ), load ( ) and effort force ( ).

2. Describe the step-by-step operation of your machine by using a flow chart, concept mapping, a list in point form or a paragraph. Begin when you initiate the operation (e.g. by dropping a weight, rolling a marble, starting a motor) and end with the completion of the task.

Below is an example of the beginning of a flow chart:

STEP 1 ____

____

STEP 2 ____

____

3. Below is a list of some forms of energy: thermal (heat), potential chemical, potential gravitational, elastic potential, kinetic, electrical, mechanical, light.

Identify which kinds of energy are involved in your machine and describe how/where they are involved. If you can, link the energy to the simple machines. Follow this example:

Work was done when ______________________________...
__________ energy was involved when ______________...

GRADE 8 SCIENCE - ENERGY AND MACHINES
Constructing a Mechanical Device
EVALUATION

Paperwork /25
- *Analysis - Parts A, B and C
- *Day-to-Day paperwork

Machine
- *Criteria 1 /10
  - -has at least three simple machines (lever, wheel & axle, pulley, ramp, wedge, screw)
  - -more than three simple machines present BONUS 1
  - -simple machines are active not passive
  - -simple machines are well constructed and work as intended
- *Criteria 2 /6
  - -performs work by exerting a force over a distance in the direction of the force
  - -performs a simple task
  - -performs more than one task
  - -task is an original idea
  - -materials are used creatively
  - -machine is reliable (performed task more than once)
  - -machine could be used again easily
  - -appearance of machine is attractive
- *Criteria 3
  - -uses a source of energy other than the chemical energy of student /4
  - OR
  - -student intervened once to correct minor "glitch" OR /3
  - OR
  - -student intervened with own energy to perform essential function for which there was no alternative OR /1

Presentation /5
- * Did machine perform task during demonstration?

Work Habits /10
- * effort made to complete work
- * worked cooperatively
- * kept on task
- * respected opinion of others
- * left work area neat

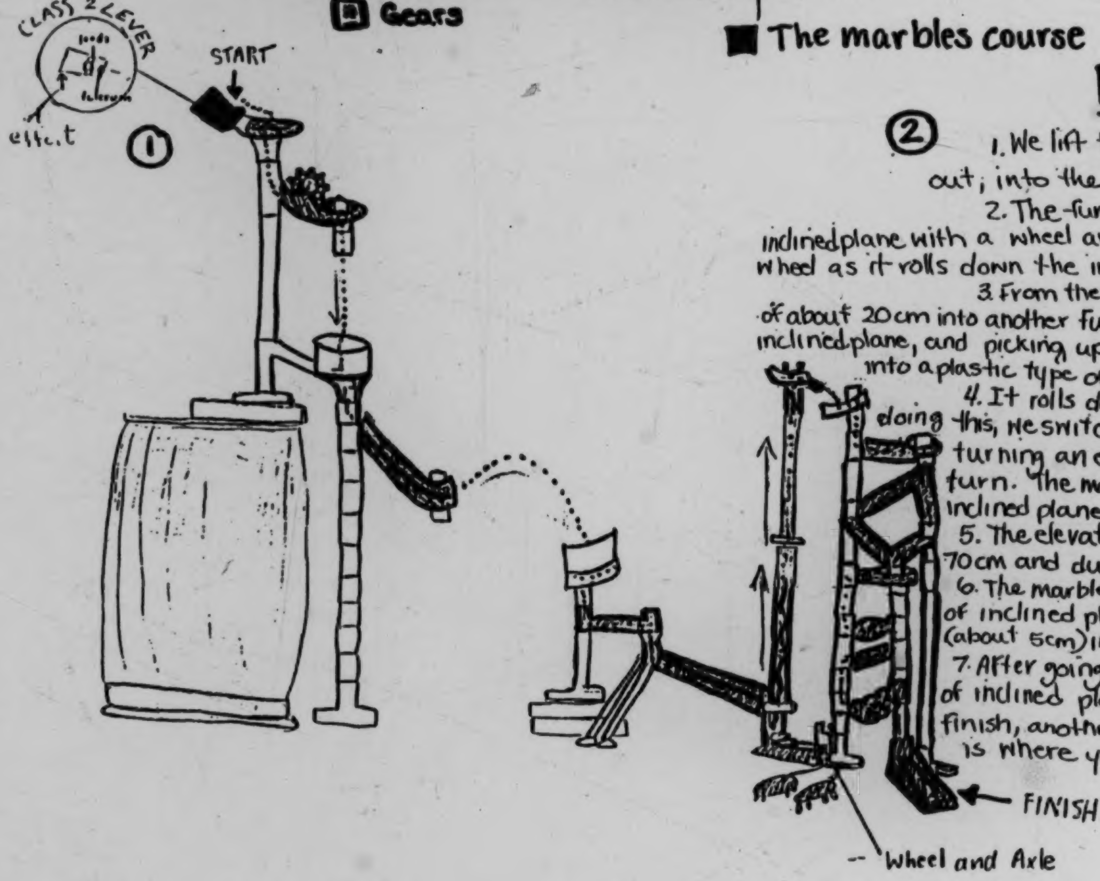
TOTAL /60

LEGEND ■ Inclined plane ■ Wheel & Axle ▣ Gears ■ Screw ■ Lever

The Candy Sorting Machine

PART B

■ The marbles course



FLOW CHART

1. We lift the lever, making the marbles roll out, into the funnel

2. The funnel guides the marble into an inclined plane with a wheel and axle. The marble spins the wheel as it rolls down the inclined plane.

3. From there, the marble drops a distance of about 20cm into another funnel. From there, it rolls down an inclined plane, and picking up speed, jumps through the air into a plastic type of slightly inclined plane.

4. It rolls down two inclined planes. As it's doing this, we switch the elevator motor on. The gears turn, turning an elastic, and making the elevator turn. The marble has just gone down an inclined plane into the elevator.

5. The elevator carries the marble up about 70cm and dumps it off into another catcher.

6. The marble rolls down through a series of inclined planes, going down small pipes (about 5cm) inbetween each inclined plane.

7. After going down there seven different types of inclined planes, the marble rolls into the finish, another type of inclined plane. This is where you pick up your candy.

A Detailed Look At Our Cactus Watering Machine

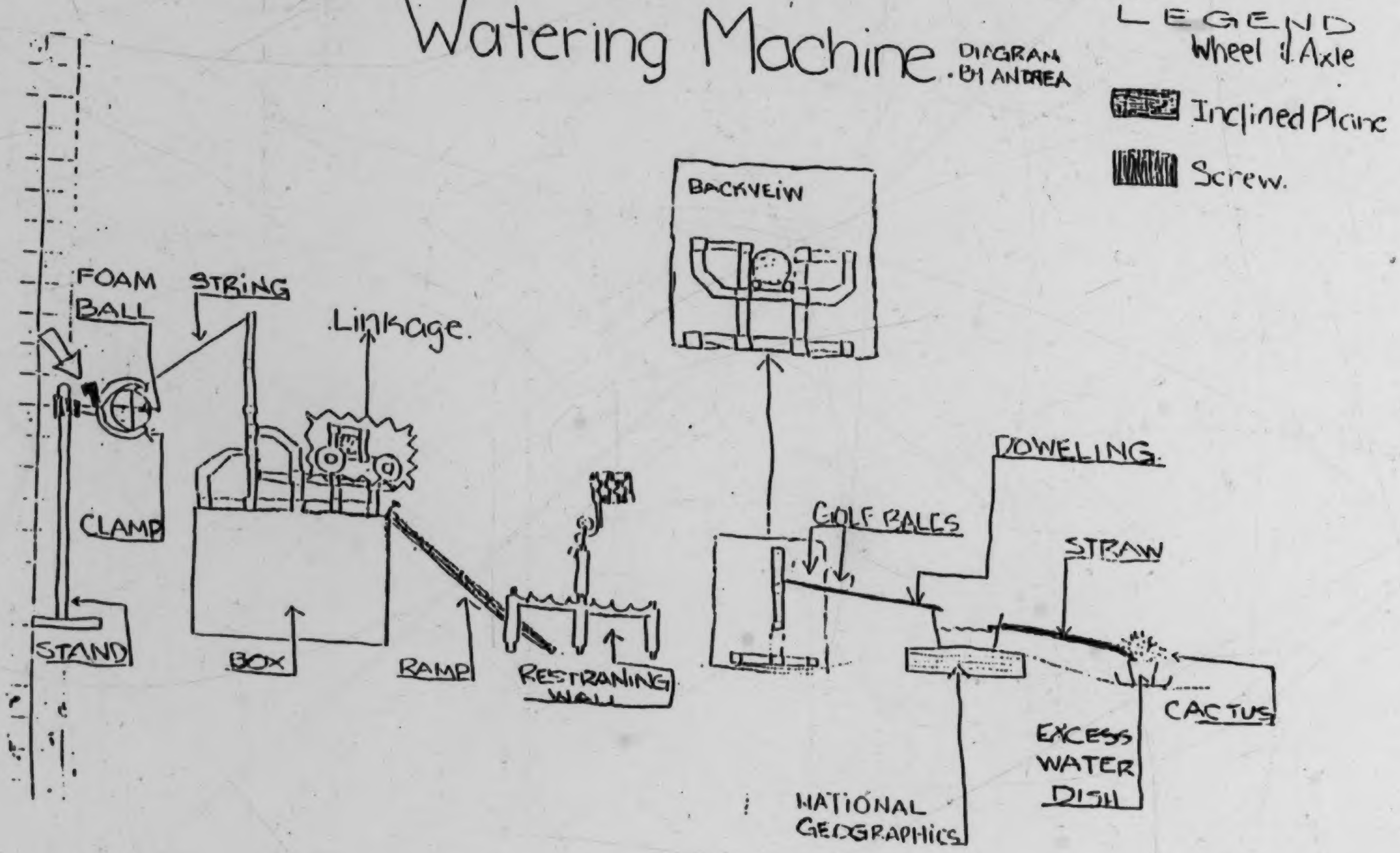
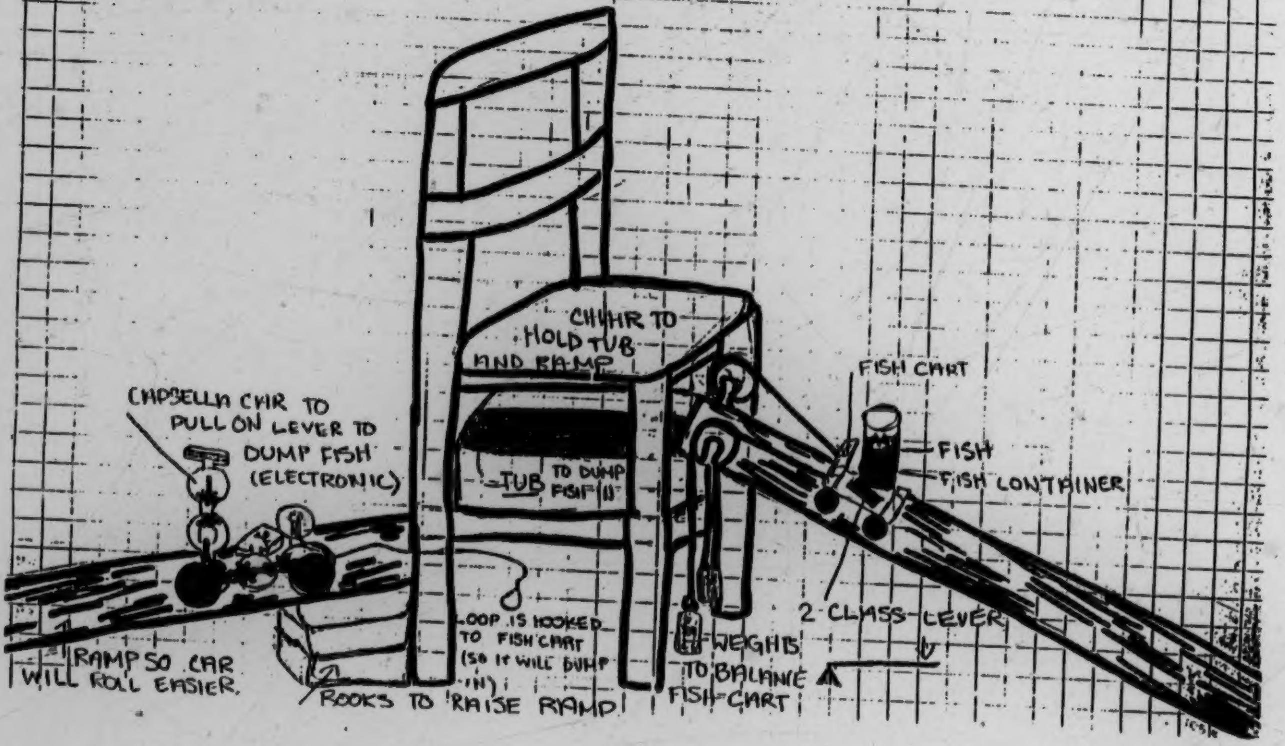


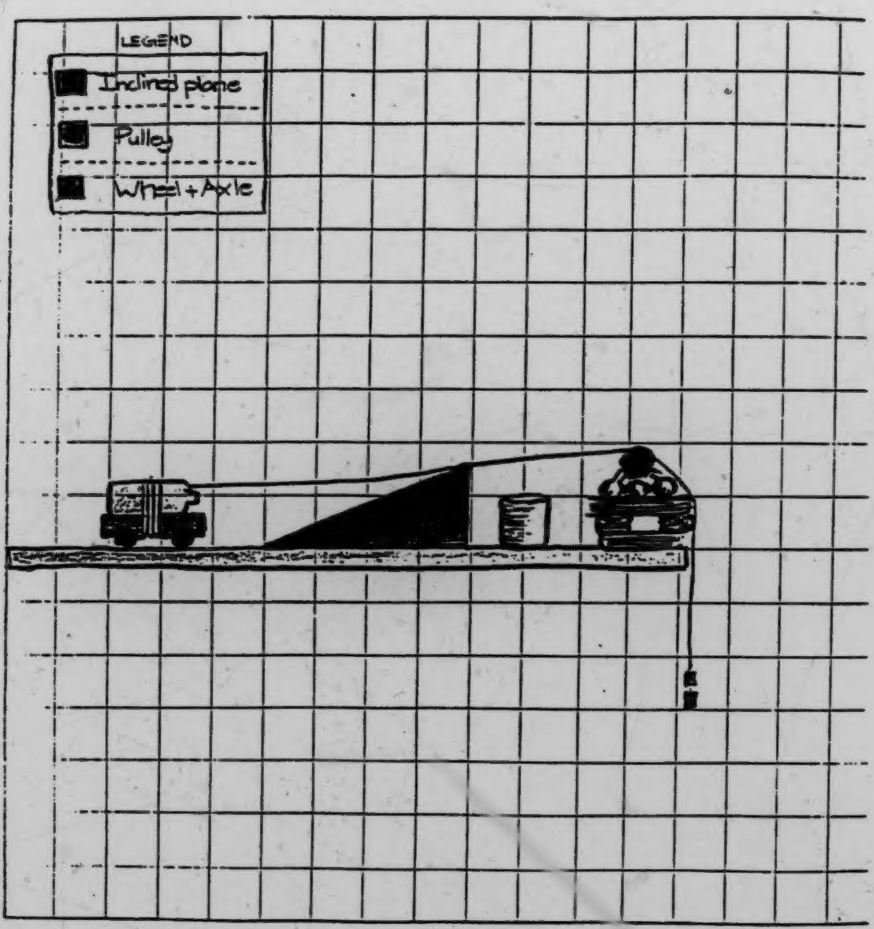
DIAGRAM BY ANDREA
LEGEND
Wheel & Axle
Inclined Plane
Screw.
BACKVEIW
FOAM BALL
STRING
Linkage.
CLAMP
STAND
BOX
RAMP
RESTRANING WALL
GOLF BALLS
DOWELING.
STRAW
CACTUS
EXCESS WATER DISH
NATIONAL GEOGRAPHICS

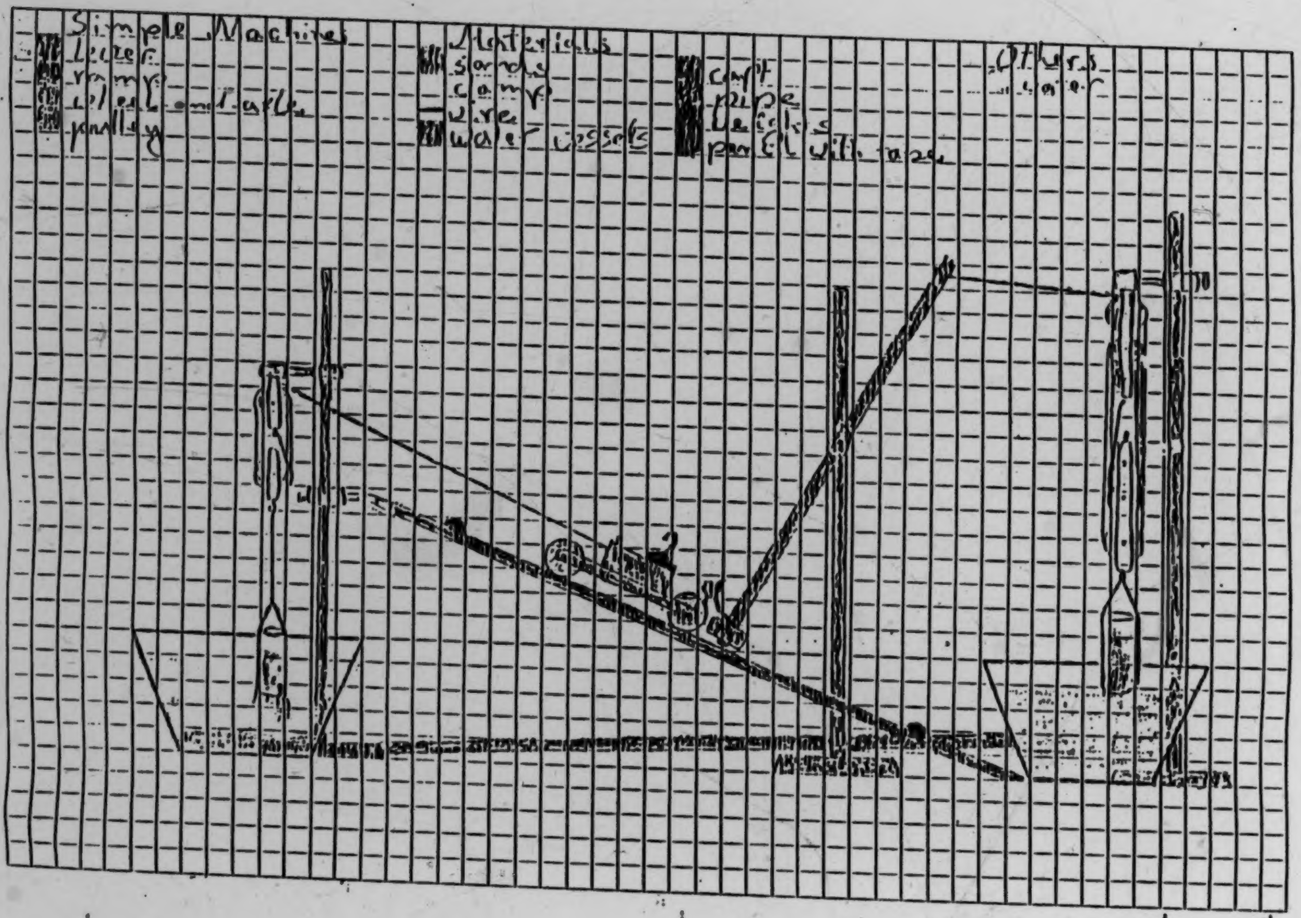
PART B-1

■ INCLINED PLANE
■ LEVER
■ WHEEL & AXLE
■ PULLY
■ GEARS

Amy's Fish Scooping Machine


CHAIR TO HOLD TUB AND RAMP
CAPSELLA CAR TO PULL ON LEVER TO DUMP FISH (ELECTRONIC)
TUB TO DUMP FISH IN
FISH CART
FISH
FISH CONTAINER
2 CLASS LEVER
LOOP IS HOOKED TO FISH CART (SO IT WILL DUMP IN)
WEGHTS TO BALANCE FISH CART
RAMP SO CAR WILL ROLL EASIER.
BOOKS TO RAISE RAMP


LEGEND
Inclined plane
Pulley
Wheel + Axle


Simple Machines
lever
ramp
wheel and axle
pulley
Materials
sands
camp
wire
water vessels
cart
pipe
blocks
pencil with tape
Others
water

and Company

flowchart

sod is put on the swich

swich makes connections and chemicall changes in side the cell to make electricity

lectricity flow to the motor

lectricity turns into kinetic energy

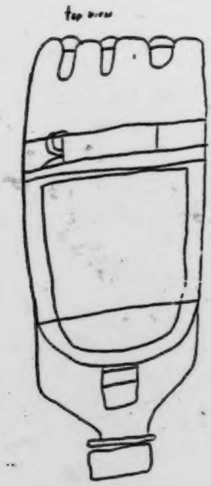
netic energy flows through multiplying gears to wheel and axel

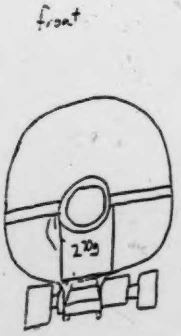
netic energy turns potential energy in wheel to kinetic energy

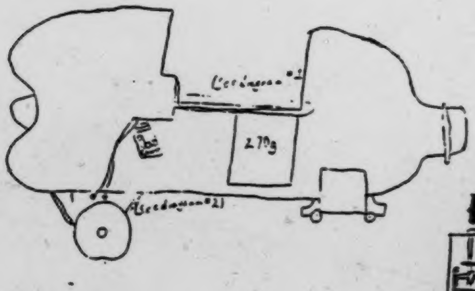
netic energy starts to move wheels

tential energy in car turns into kinetic energy

car starts to move






See diagram #1
270g
See diagram #2

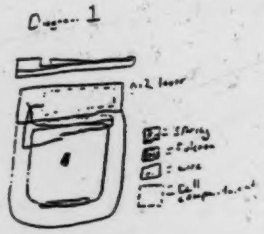


Diagram 1
on 2 lever
= Spring
= Foleoon
= wire
= Cell compartment

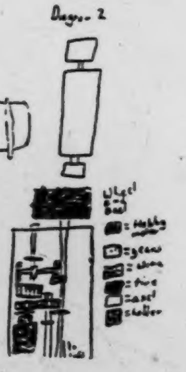
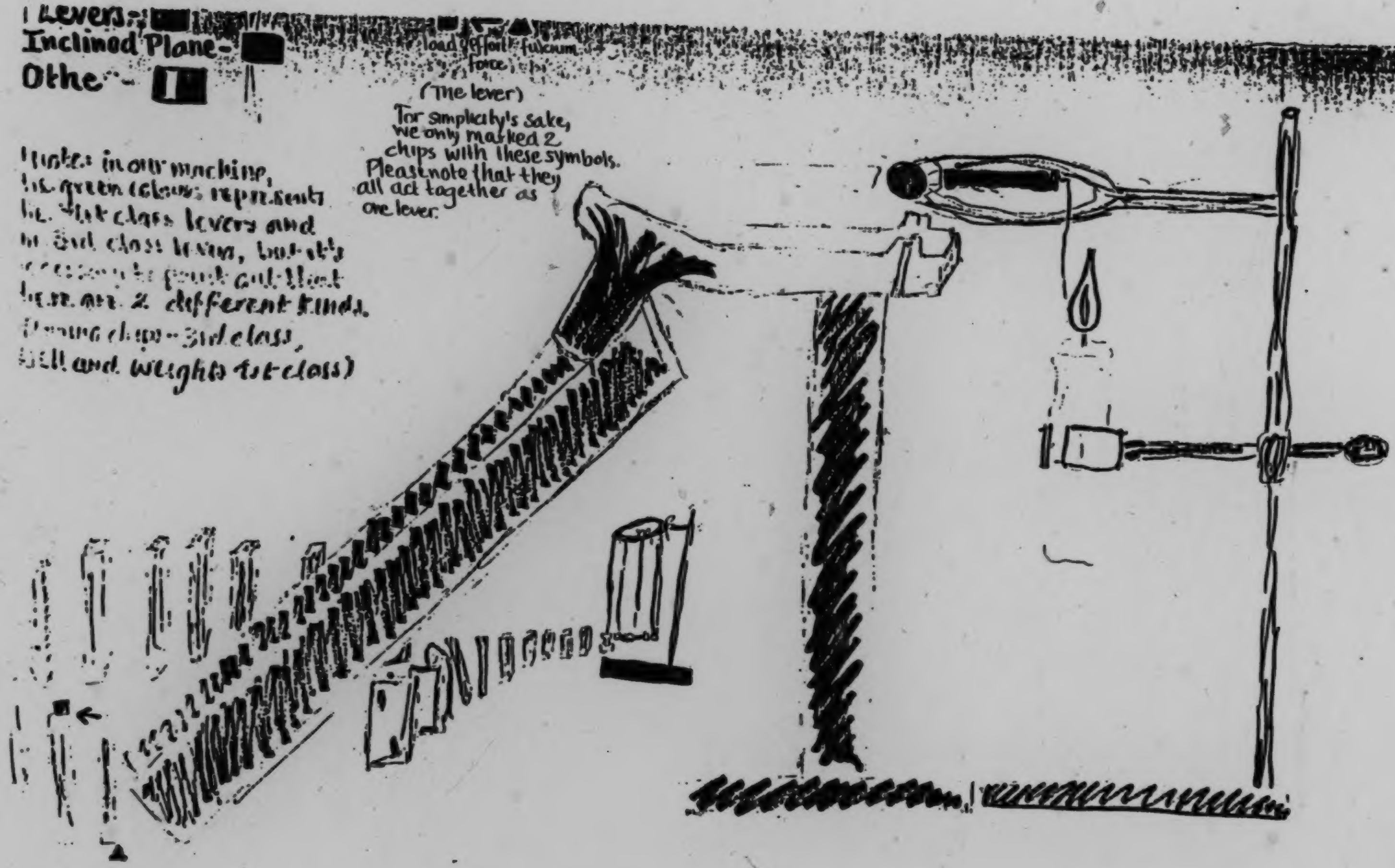


Diagram 2
Wheel
Back
= Hobby motor
= gears
= wire
= tire
= axel
= shaller

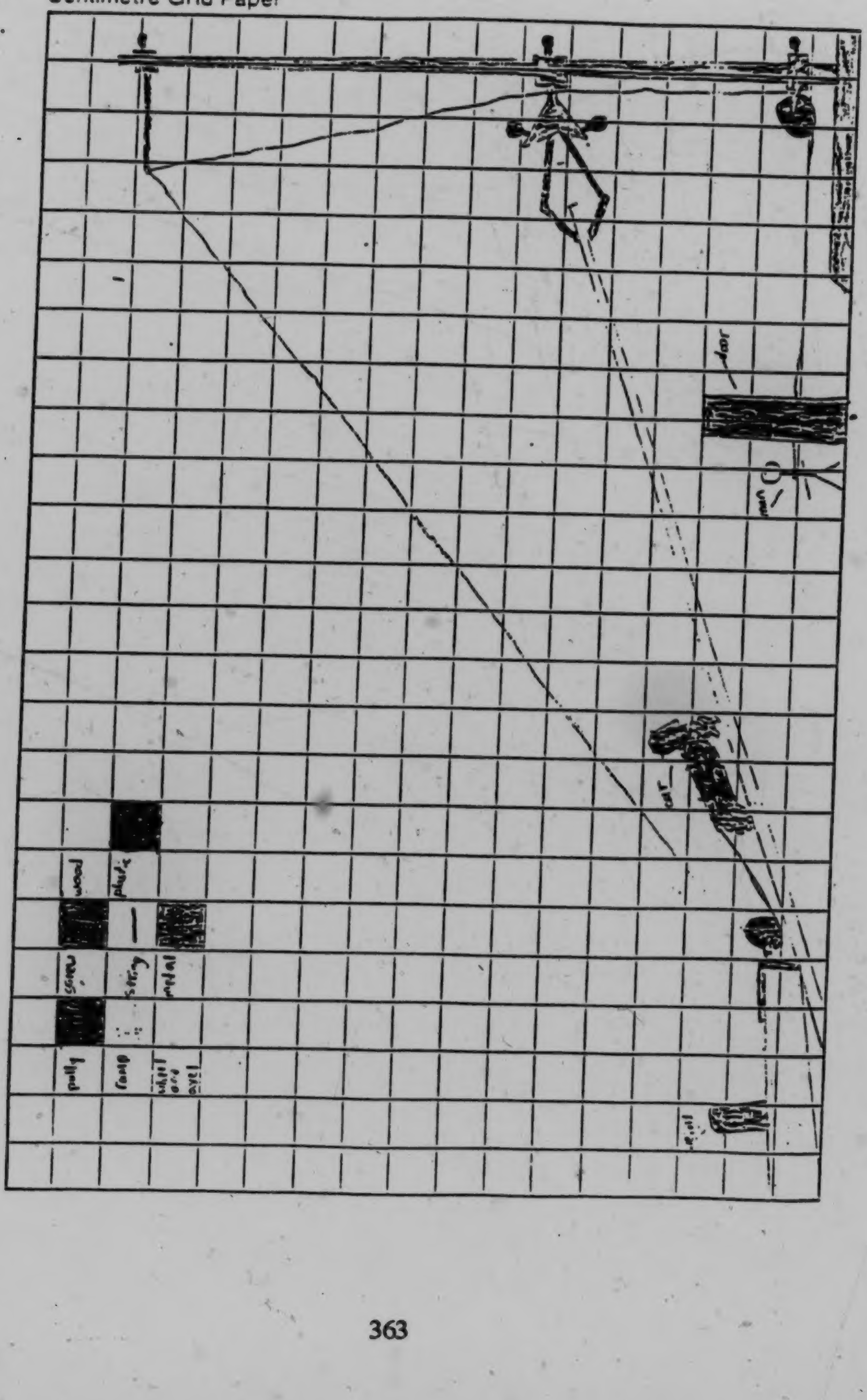


Levers -
Inclined Plane -
Othe -
load
effort force
fulcrum
(The lever)

For simplicity's sake, we only marked 2 chips with these symbols. Please note that they all act together as one lever.

(Note: in our machine, the green colour represents the 1st class levers and the 3rd class levers, but it's necessary to point out that there are 2 different kinds. (Domino chips – 3rd class, bell and weights 1st class)

Centimetre Grid Paper


pully
screw
wood
ramp
string
plastic
wheel and axel
metal
door
man
car

Part B ①

Part B

Master 4

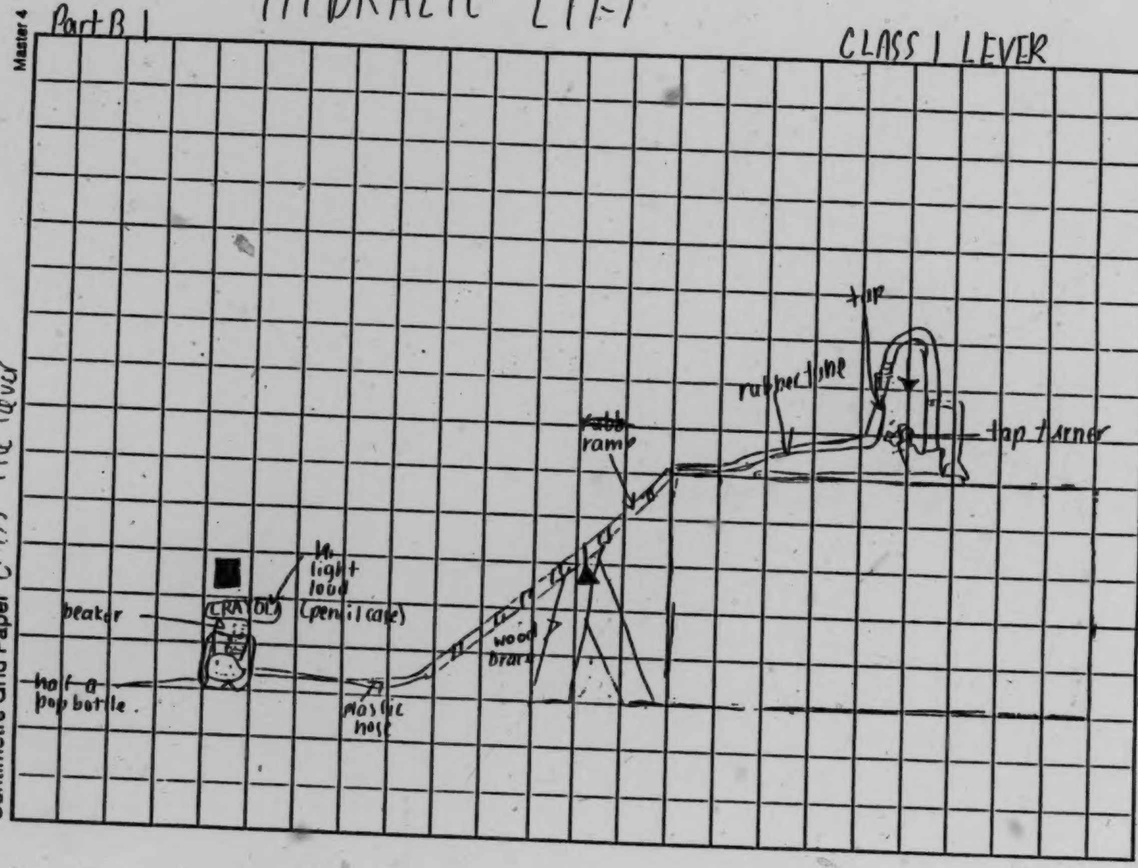
Part B 1

HIDRALIC LIFT

CLASS I LEVER

Centimetre Grid Paper

(i.7.) the lever



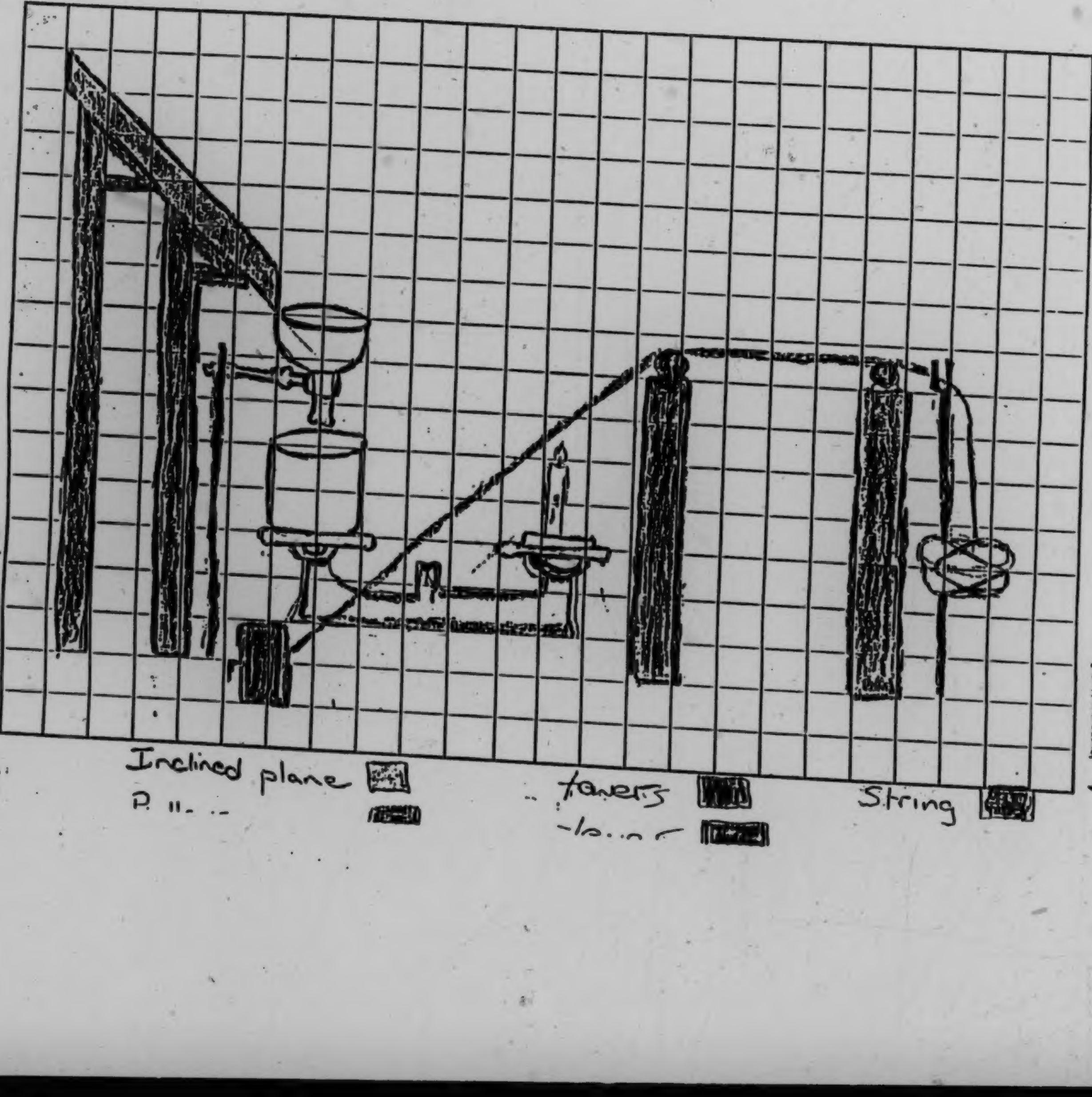
tap
rubber tube
~~rabb~~ ramp
tap turner
light load
CRAYOLA
(pencil case)
beaker
half a pop bottle.
plastic hose
wood brace

© Ginn and Company

Part B

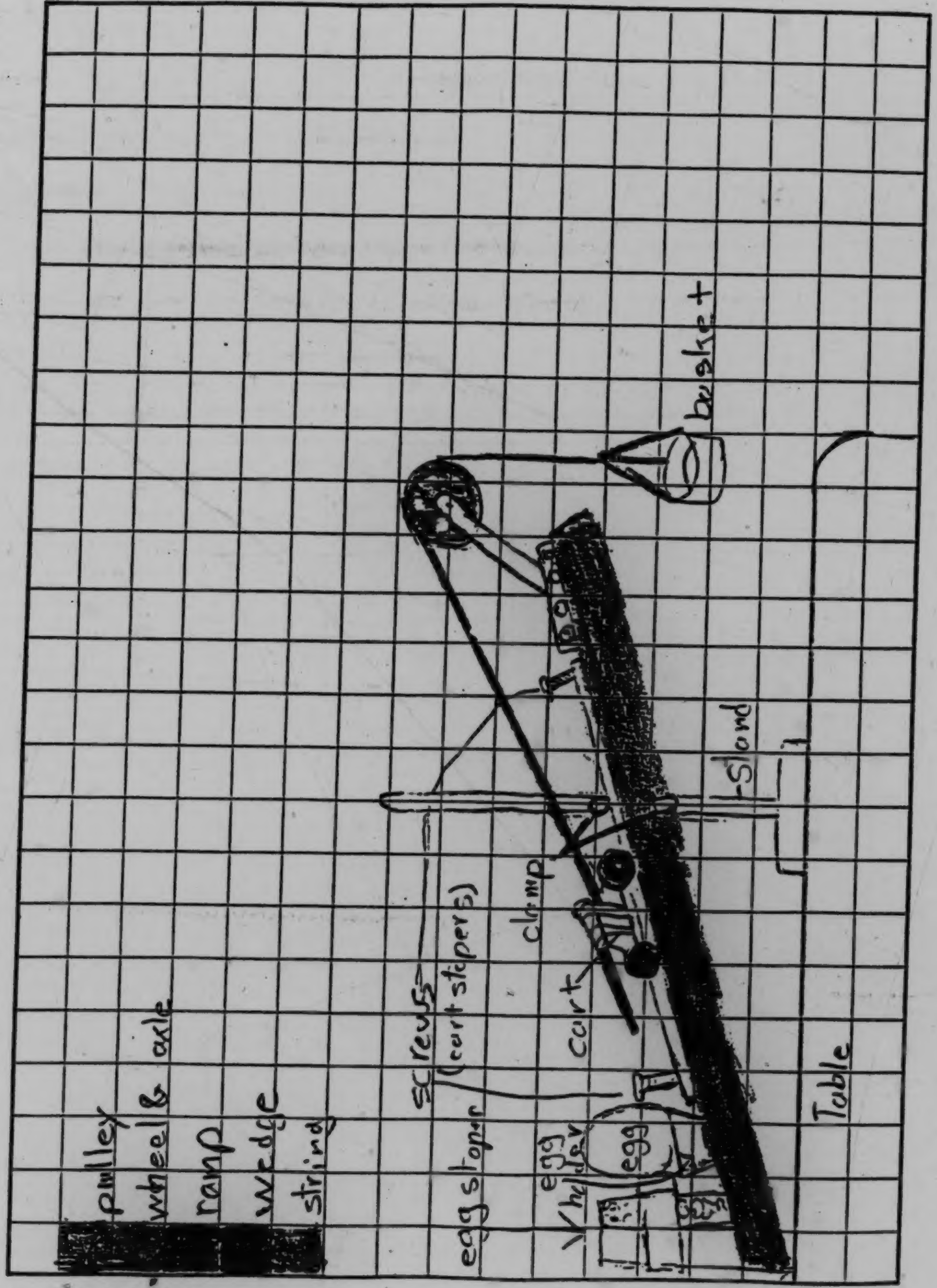
(I)

Centimetre Grid Paper

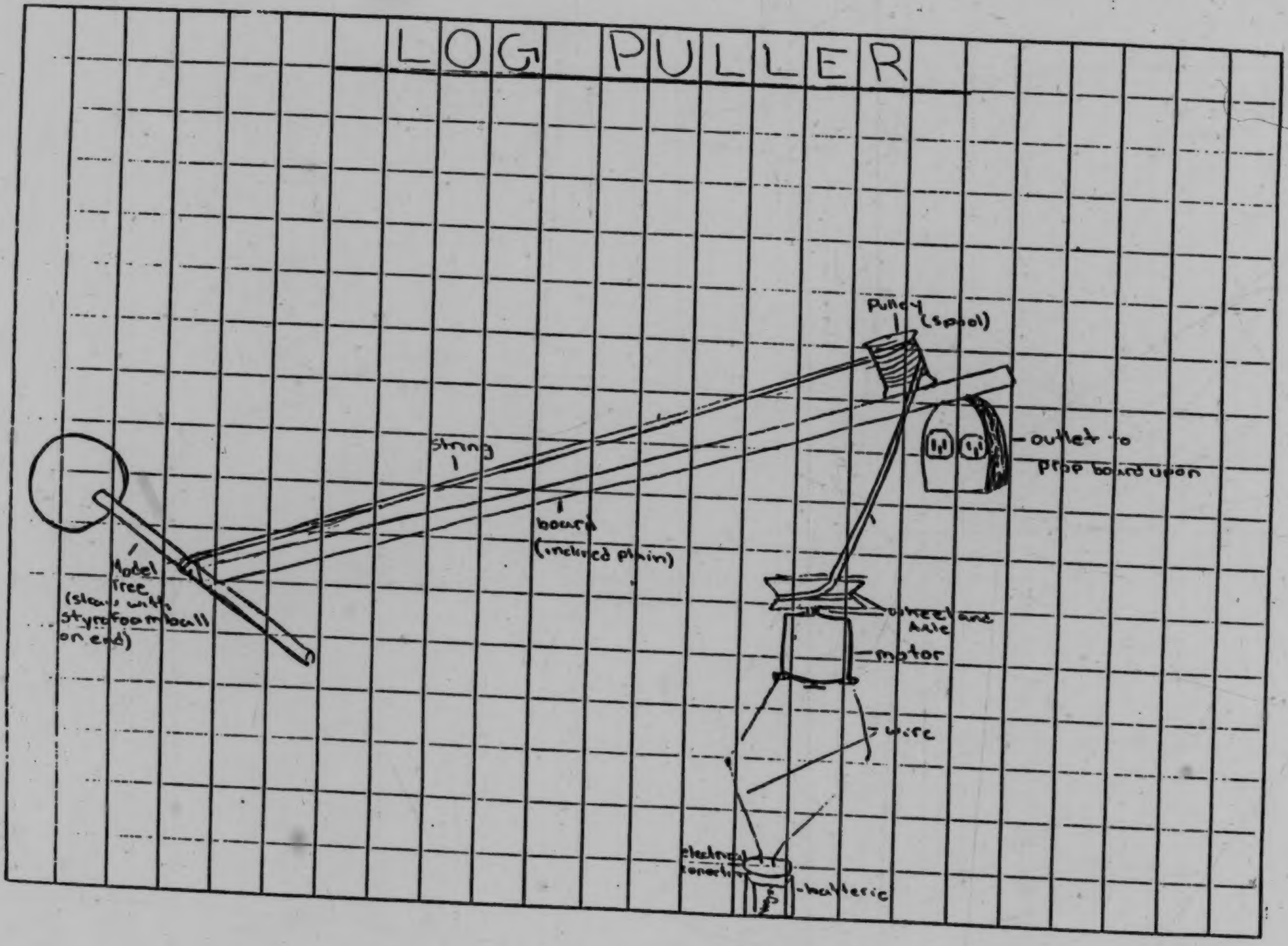


Inclined plane ▨
P[illegible] ▨
towers ▨
[illegible] ▨
String ▨

Centimetre Grid Paper

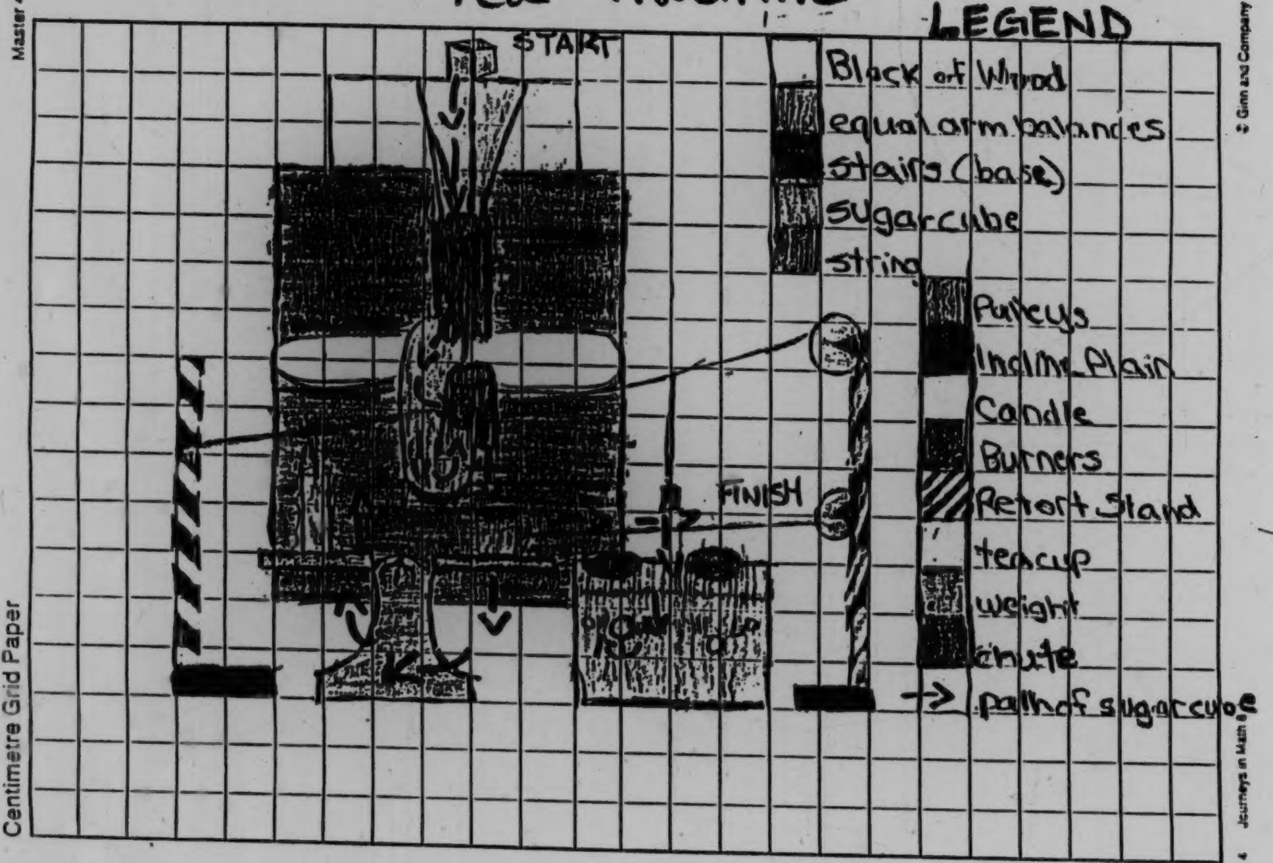

pulley
wheel & axle
ramp
wedge
string
screws
(cart stopers)
egg stoper
egg holder
egg
cart
clamp
stand
basket
Table

LOG PULLER


Pulley (spool)
string
board (inclined plain)
outlet to prop board upon
Model Tree (straw with styrofoam ball on end)
wheel and axle
motor
wire
electrical conection
batterie

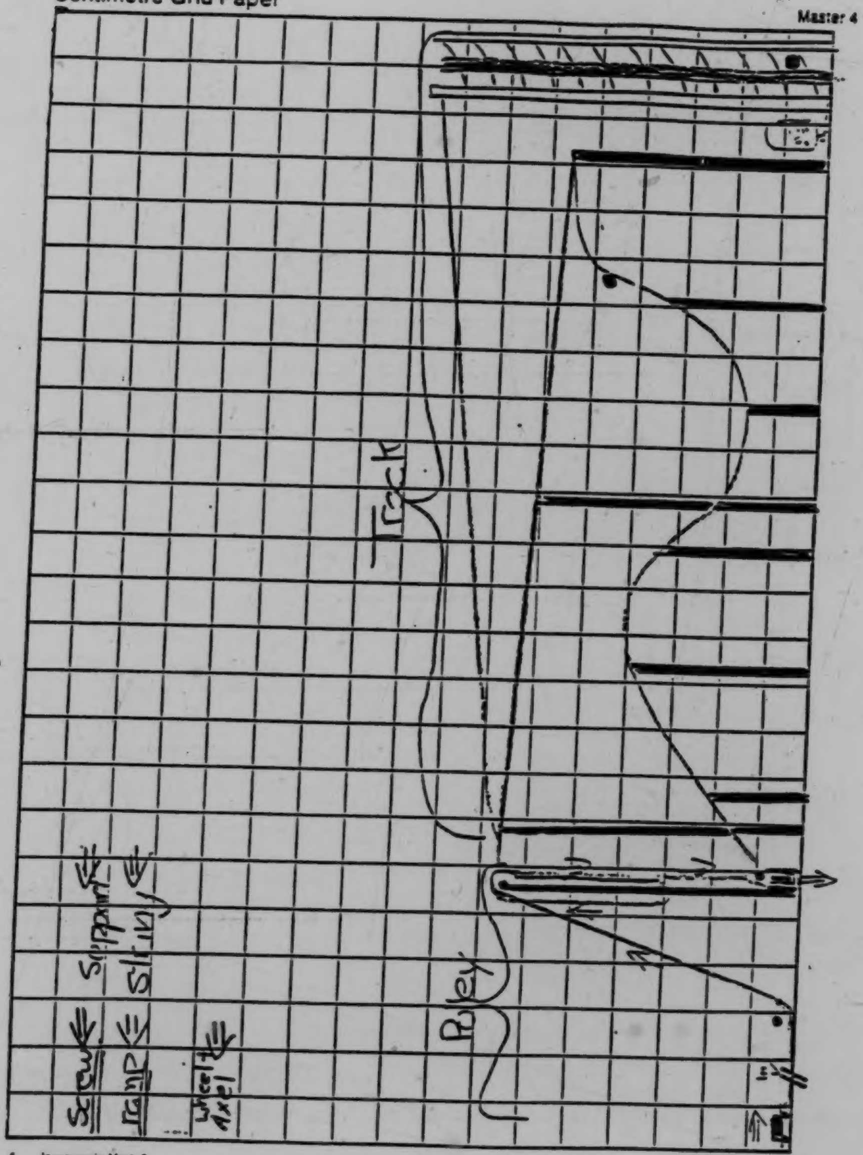
Lazy Persons Tea Machine

PART B (1)


START
FINISH
LEGEND
Block of Wood
equal arm balances
stairs (base)
sugarcube
string
Pulleys
Incline Plain
Candle
Burners
Retort Stand
teacup
weight
chute
→ path of sugarcube
Master 4
Centimetre Grid Paper
© Ginn and Company
4 Journeys in Math

Centimetre Grid Paper

Master 4



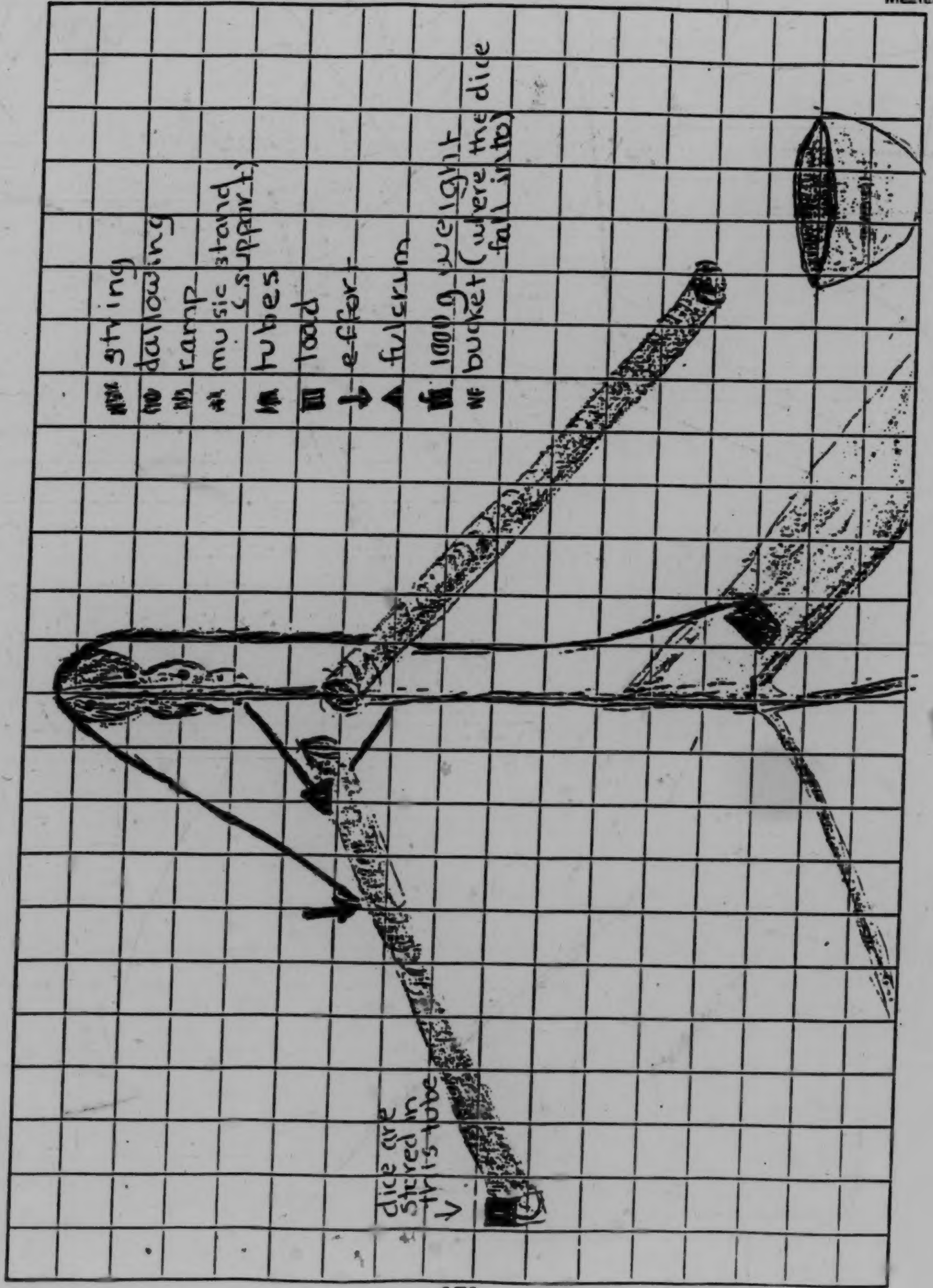
Screw
support
ramp
string
wheel + Axel
Track
Puley

© Ginn and Company

PART D - Graph

Centimetre Grid Paper

Master


string
dallowing
ramp
music stand (support)
tubes
load
effort
fulcrum
1000 g weight
bucket (where the dice fall into)
dice are stored in this tube

GRADE 8 SCIENCE - ENERGY AND MACHINES
Constructing a Mechanical Device
Compilation of Class Responses

Part A - An Overview of your Machine

In the first paragraph, describe the task your machine performed. Was this the task you originally designed your machine to do? How well did your machine function in performing the task? What, if any, were its faults?

In the second paragraph, describe the specifications your machine met. Were these the original specifications you wanted your machine to meet? If your specifications changed, explain how you changed them.

Linday & Sasha Our machine performed the task of dispensing candy. This is what we originally planned for it to do. We wanted the marble to travel over a length of at least one and a half meters. Originally we wanted the marble to go down a long ramp at the end until it reached floor level. But we decided not to do this because the marble would pick up too much speed and bounce out the end. Our machine did a really good job of performing this task, but there was only one minor fault. The marble didn't always go into the elevator. Sometimes, if the rampwasn't in it's exactly right location, the marble woudn't get into the elevator and go up.

We wanted our machine to carry the marble over a length of one and a half meters. It did. We also wanted it to keep the candy in one piece, but we ended up using marbles to represent "jaw breakers" because we didn't have time to call the candy stores and go pick up the right size.

Tony The tasks my machine preformed were two - first to lower an empty can into a small pool and secont to lift the can full with water. My oreginal idea was a machine for sorting different types of balls but it required too much materials. My machine worked pretty well. The lever got stuck between the wheels of the cart (see second diagrm, page 3) so I had to reconstruct the machine, the two cans got soft from the water.

The wire had to be strong enough, the pulleys had to decrease the effort force by at least 1/3, the lever had to be very mobile.

Leena & Samantha The task of our machine was to drop a sugar cube into a cup. The cup was then to be moved over onto a burner so it could be heated up. This was the original task. In our presentation, the sugar cube got to the cup. The weight was supposed to fall on the string attached to the cup, which was to have made the cup move onto the burner. The weight didn't fall. We were relying on the force to do two things, but it didn't have enough power so we added another counter force. The pulley's groove was not deep enough to hold the string.

The cup had to be placed directly under the second chute for the sugar cube to fall into it. The weight also had to be precisely placed above the knob of the burner to turn it on. The string had to be placed high enough, so the flame of the candle wouldn't reach it too early, but could reach it when the equal arm balance weight shifted.

Amy I built a fish scooper. The task it performs is to carry the fish up the tank and scoop it in. Originaly it was going to take the fish OUT of the tank but then I realized my problem that the fish would swim away unless it was dead, and even dead fish are hard to scoop out (believe me, I've tried). This was why I invented the fish scooper, actuly its probably more like a fish dumper, because my new modle dumped the fish in. My machine functions quite well (in its finished state). Its only minor problem was how fast the fish went up the ramp. I couldn't control the speed very well because it was pulled up by a pully and even though I had ballanced the weight and the fish cart on an equal arm balance it still went up either too fast sometimes or if it went to slow it wouldnt make it to the top. If I did a third design on my machine I would use a moter to pull the fish up.

Originaly I was going to use a real fish. So these were the specifications my machine had to meet:
- it had to carry the fish up to the tank (15 inches).
- it had to keep the fish safe.
- it has to be able to carry a load as heavy as the fish, cart and water.
- to dump the fish IN the tank, not miss and dump it on the floor.

As you can see alot of these specifications have to do with the safty of the fish. Then Sarah pointed out to me that you can't just dump a fish in a tank, which is true. They have to be let in slowly. So it was then decided to use a fake fish. So my specifications changed to this:
- having to carry the fish up the ramp.
- dump the fish in a tank.
- having to carry a load as heavy as the one I had.

Sharlet & Kandy The task our machine was supposed to perform was to ring a bell by using a wind up toy to push a ball across a 35 cm distance, drop the ball into a hole, then roll down an inclined plane, hit a class 1 lever, roll into a basket suspended by a pulley, and then pull the weight on the other side up as the basket hits the bell.

Originally we wanted an egg to be held on a car with an inclined plane, moved 30 cm, roll down the inclined plane and into a hole. Then we changed the egg to ball because we were afraid that the egg would break. Our next problem was that we couldn't find a car with the inclined plane. Then, we wondered bout how we could get to stay on the car so we changed it to just having a wind up toy push the ball.

Another problem was that when the ball dropped down the hole it didn't always hit the lever, so we added an inclined plane on which the ball rolls down then hits the lever and rolls into the basket. We also had a problem with the pulley because we had planned to have a basket of marbles on the other side, but the marbles kept shifting wieght so the fishing line that held the basket on, kept on sliding out of the groove.

The specifications our machine had to meet ddin't change too much, even though the machine went through many changes. The only specification that did change was the distance the wind up toy had to push the ball (we changed the distance from 40 cm to 55 cm). The next specification was that the ball had to drop down 4 cm, roll down an inclined 4 cm long, drop another 7 cm onto a class 1 lever, then roll 3 cm off the lever and into a basket which will pull the 39.7 g wieght up and when the basket goes down it will ring the bell.

Sharon My machine was an elevator. It's task was to lift a can up in the air by using water as the chemical energy to turn the water wheel that moves the elevator up. This was the task that I had originally planned the machine to do and it worked well. The machine ran smoothly, although sometimes I had a bit of trouble with the water wheel in that it sometimes did not have enough water pressure so it wouldn't turn. I overcame that fault.

The specifications my machine met was that it had to lift a can 70 cm in the air and then push it off a ramp at an angle of about 140°. Yes, these were the original specifications my machine was supposed to meet. Except I had planned to make it go down again. That was the only thing I had to change. When I changed all I had to do was not try to lower the elevator.

Vance & Cameron Our machine release a miniture car from a ramp and unloads a marble into the marble works. This was the original task we wanted it to perform. It worked well when we corrected all it's errors. Some of the problems were that the car kept on falling apart. Also the marble didn't fall in the right place when it was unloading.

The specification our machine is that it had to have enough force when its coming down the ramp and a sudden stop, so that the marble will fly to the marble works. Our idea did not change since the beginning.

Brian The task that my machine was to pull a car across a 1 m surface. My problem was when the ball that came off the track it missed the bucket that it was supost to go into. My design was original.

My machine specifications were that my machine met was to pull a sertain load across a 1 m surface. My specifications were original too.

Katty & Anne The task our machine was designed to do was to ring a bell. This was the task we had originally planned for our machine to perform. In our experiments, the machine worked, and it passed all the requirements we had said we'd meet, although we had to adjust the parts slightly, but when we did the actual presentation (to the class), the machine failed the test. This was because our machine was unstable, and with a slight shake of the table the parts of the machine would need adjustment because they would be knocked out of place.

The specifications our machine had to meet were the following. Primarily, the bell had to be rung. To meet that goal, the small candle had to burn to the end, therfore melting the wax on which the glass marble was positioned on. The glass marble, in turn, had to fall into the funnel, down the ramp, and then it would have to knock over the first domino chip, which would knock the next, and so on. Finally, the last chip, had to hit against the rod hanging beside it, which would hit the weight on the other side, repeatedlybouncing off, and therefore ringing the bell multiple times.

We made a few significant changes to the original design: we added a funnel and a ramp so that the marble would be directed to fall on the first domino chip and not just anywhere.

Johnny & Dave The task that our machine performed was to power a car with batteries amd a motor and bumt into a curb (wood). A golf ball would then run down an inclined plane which was on the front of the car. The golf ball would roll across the piece of wood and fall into a cup which was tied to a pulley. When the ball landed in the cup it would go down the pulley and send a 50g weight upwards.

All the specifications to our last idea were met. The car must go 40 cm and must have stoped in a way that the golf ball which was on an inclined plane attached to the front of the car rolled down it. It must have travelled in a forward motion and landed in a cup attached to the pulley. These specifications were all met. The original idea didn't meet all of it's specifications though. It was supposed to pull a heavy weight a long distance but the car was unable to do that because the car didn't go fast enough and didn't have enough power.

Lorisa & Lavana Our machine was a dice roller. Therefore, it rolled dice. But, this wasn't our original idea. The original design was an alarm designed to wake you up. We had 2 ramps and a lever. This did not meet the standards that were set. So we went on to our next idea. The dice roller worked well but to make it better we added a few extra supports and ideas. One of the faults was that we had to design a weight that goes down a ramp instead of using chemical energy. The other fault was that the dice would not go through the tube so the tube had to be shifted and moved to different places.

The specifications it had to meet were that the dice had to go from the first tube into the second tube. The first tube also had to fit into the second tube. The weight had to go straight down the ramp so the string would stay on the pulley and pull the first tube up. The string had to be securly taped to the tube so the weight wouldn'r pull it off. Before we built the machine, we did not realize that so many complications would occur. We thought that the weight would pull the tube straight up with the string staying on the pulley. The weight had to be fitted on to the ramp so it would go straight down. The weight had to go straight down in order for the string to stay on the pulley. The string had to be securly taped to the tube so the tube could be pulled up. The tube had to fit into the other tube so the dice would go through.

Andrea & Janesta Our task was to water a cactus or other plant. Our first task was to ploish a doc Marten then we switched ideas. Our next idea was to fill a container with water. Then we dicided on our third and final idea, a "cactus watering machine." Our machine worked well on the first few days of the project. Throughout the rest of the project a few small flaws ocurred and we fixed them. The faults were few but when they occurred it caused trouble for us.

Fault #1: We didn't have enough simple machines.
#2: Our cardboard tube got soggy and collapsed.
#3: Sometimes the golfballs didn't move.
#4: The cactus got overwatered.
#5: Sometimes the pendulum hit the side of the stand.
#6: The ramp fell down sometimes.
#7: The National Geographics got wet.
#8: The plastercine got gooey.

Our machine had to work so that the clamp gripped the pendulum so that when released the pendulum hit the car and made it move. The car had to be properly aligned so it didn't get stuck. The ramp had to stay up so that the car could go down it and gain momentum. The platform that the sticks were on ahd to move slightly to start the golfballs rolling. They had to jolt enough, so that they both would roll in the water. The balls had to be large enough so that they displaced enough water to go through the straw and water the cactus. Although these were not the original specs. Our machine still worked. We had to add a clamp, because we needed a 3rd simple machine.

Keith My machine was to move a 700g mass 3 m. This was the original task and I think it worked quite well. The toy car and drive axal where put on crooked and that caused it to turn right.

My machine was to transport 500g over 3 m and further. The specifications are those I wanted in the first place. The original mass was to be 500g, but I uped it to 700g because I thought it would handel it, and it did.

Tim & Mark The task of our machine was for it to be able to move a load a certain distance. Our machine is a car that is powered by CO_2. And it will weigh under 700 grams without the extra weight of 200 grams.

When you told us that we could make a machine Tim and I both had the same kind of idea. He wanted to do something with a rocket launcher and I wanted to do something with a car. When we started to work together we decided on using a car that would move a load of 300 - 400 grams. But that was not a good weight for the car. So we changed it to 200 grams ao we could put 100 grams on both sides. When we were making the car we had 2 simple machines already built into the car. But we needed three. We started to try and make a pulley. After many classes we found that a pulley system was not a good idea. So we decided to make a wide wedge so that the air that was going to hit the car be reflected up so that the car would be more air dynamic. After some changes our car was done. It was almost what our original design was, but much lighter. However the task did not change at all. But we di have a few ideas about how to do it different, in the end we used the first task.

When we did our first test in the hallway the car worked very well. But it did not travel straight. Then when we did it in the class it did not seem to work. I thought that when we did it in the hallway we did not have any weights in it, but Tim said that we did. I do not know why it did not work too well in the class but I think that the weight was much less in the class, then it was in the hall.

Our machine did not meet all of our specifications that we wanted it to in class, but it did in the hall. It carried a weight and it went over 20 meters. When we finished the first design it did take the impact of a fall from the table and running into a wall. So that part went good. There might have been one other reason that our car did not work in the class. That might have been because that we had to make 2 holes into the canister. The first one that was made was too small. The second was too big. This was most likely the reason that the car did not work well in class. I think that if we got Mr. T. to make the hole that the car would have moved 20 meters and it would have met all our requirements. All of the things that we wanted the car to do did not change when we were working on our car.

Mari The task of my simple machine is to dispense little beans into a cup. The way I was going to have the beans drop into a cup was originally the way I had it planned, but I changed parts of how the machine worked to do the task. I had problems with trying to make a fulcrum for a lever that moved easily but stayed in one position on the surface instead of pivoting around the place. I also had trouble trying to lift the 100g mass off the lever so that the beans could dispense, without using chemical energy. It took a lot of thinking, re-building, and re-creating to make my machine working, and it worked quite well once this was done.

There are some specifications my machine ha to meet in order to function properly. The pendulum (which is the starting point) has to be swung hard enough to hit the large ball (with a mass of 30g) so that it will roll down a rigid inclined plane tilted at a 30° angle, and bump into a 200g mass. The mass must then drop off the edge of the ramp. As the 200g mass is tied on a string and is connected to a 100g mass, when the 200g mass is dropped, it lifts the 100g mass off a lever on the other end of the machine. When the 100g mass goes off the one side of the lever, the beans placed in a half-bucket on the other side of the lever is heavier, and it tilts downwards, sending beans down a 3 cm ramp and dispensing into a cup.

Sheena My machine lifted a toy wagon, and also pushed a toy car over a distance of 10 cm. Originally I intended my machine to push the toy car over a distance of 50 cm, but the force of the rolling marble was only strong enough to push the car for a distance of 10 cm. Thus, I had to change the distance to 10 cm.

My machine's specifications are the following:

- when the marble is dropped into the first wagon, the wagon must roll down the ramp.

- when the first wagon rolled down the ramp, the string attached to its handle must go over the two pulleys and lift the second wagon at the bottom of the machine.
- once the first wagon reached the end of the ramp, it must tip and drop the marble onto the second ramp.
- the marble must roll down the ramp and push the toy car which must be placed at the bottom of the ramp.

Originally, I planned to use a class 1 lever instead of the second ramp. However, with the materials I had, constructing a lever was too difficult, so I decided to use an inclined plane instead of the lever.

Ricardo The task my machine did was when you put a heavy weight in the cup, it goes down, unwinds a pulley, and pulls a little cart across a string. My machine is not what I had originally designed, the original task was imposible, so I designed this machine, and it was virtually flawless. The only flaw was I had to put a lever to pull the cart across the string.

My machine met all but one of the specifications. As you have already read, the only flaw was with the lever to pull the cart across the string. I replaced the lever with a pulley.

Part C - Reflecting on the Process (write paragraph answers to each of the following questions:

1. What do you like about your completed project?

We liked the way it performs such a fun, amusing task. We like the prize at the end (candy). We also like the way it looks. It's fairly attractive and also sparks people's curiousity and interest when they see it. - **Linday & Sasha**

I like my idea and I like that I planned and constructed it by myselve. - **Tony**

Our machine had a useful purpose. It would have worked completely if we hadn't taped the string with the weight to the Retort stand. - **Leena & Samantha**

My partner and I like our machine because of the process and how it works. We also like that it worked. - **Deani & Karisa**

I like the plastic fish and how it got up into the tub. It was also neat when the cup acctuly dumped over. - **Amy**

We like the wind-up toy idea and we like the fact that it actually works. - **Sharlet & Kandy**

What I like about my completed project is that it works. Also I am proud of the effort I put into it and the time and thought. It was my very own idea and I thought it through with very little help. - **Sharon**

I think our project works well, but it's kind of ugly. - **Vance & Cameron**

I like my project because it's origenal and exciting. - **Brian**

Kathy feels that we worked oor hardest on this project and we met all the requirements, as well as we could, and she also feels that it was successful even though it didn't succeed during the presentation. I, on the other hand, think thatthis project could have been improved and perhaps had a higher successrate had we had more time to work on it. However we both learned and enjoyed this project and we thought that it was more useful than one that we could have done from the book, one that would have an already designed procedure. - **Katty & Anne**

We liked the fact that our simple machine actually. We also like that our machine isn't too simple and we like the design. - **Johnny & Dave**

We liked the originality and the idea that it works. Our machine has an unusual design that makes it special. - **Lorisa & Lavana**

What we liked about our completed project was that it works and it is an original idea. - **Andrea & Janesta**

I liked the way I worked around using new products and really like the fact that it drives. - **Keith**

The reason my group made a car is that we like seeing things go fast or move. What I liked the most about my completed project was how much it improved over the course of the week. Our project went quite smoothly with only a few problems related to the third simple mahine and the power source. - **Tim & Mark**

The lever where the 100g mass lifts and dispenses the beans is what I like most of all of my machine. I think this is probably because I worked the most on that part to try to make it work. I also liked my final idea of having a ball drop the 200g mass and lift the 100g mass on the other end because without this part functioning correctly, my machine would not be working. - **Mari**

When I began my project, I didn't think I could complete the task. However, as I slowly worked towards finishing my machine, I realized that it wasn't an impossible task. - **Sheena**

I guess the thing I liked most about my machine is that it worked. - **Ricardo**

2. What strengths about yourself or selves did you discover or affirm while doing this project?

We discovered we work really well together. We're both good at sharing our ideas and giving and taking (giving our ideas and accepting the other person's idea as well). - **Linday & Sasha**

The strength I afirm while doing this project was that I like to build machines. - **Tony**

We discovered that we worked well together and we got things done. We both shared ideas and worked on our problems that we faced when we were building our machine. - **Leena & Samantha**

We learned that we can measure well and that we can make a real machine if we put our minds to it. - **Deani & Karisa**

I discovered that I came up with fairly creative ideas. I used my time well, which I didn't know if I would be able to do, but since we only had 1 week to compleat our machine I had to work quickly and effeciantly. I rememberd to bring my matierials, and though I ran into problems I found my way around them. I discoverd that this project is alot harder than it sounds. - **Amy**

We discovered that we can build a machine, something neither of us could do before, and we learned how to use a glue gun. - **Sharlet & Kandy**

I discovered that I have the patients to complete something and make it work. - **Sharon**

Our strengh is that we can perfect little parts of the machine after it was created. - **Vance & Cameron**

I found one of my strengths is I'm good at making a plan in my head. - **Brian**

We found that we are patient, hardworking, agreeable people, who when they have their mind set on something they do all in their power to make it a reality. - **Katty & Anne**

We found out that we can use motors and we know how to use them very well now. - **Johnny & Dave**

We discovered that if we try hard and cooperate, we can be very successful. - **Lorisa & Lavana**

That we can work if we really try and that after a while things just "mold together." - **Andrea & Janesta**

I liked the multi talented approach that I used, I think that it worked out. - **Keith**

While working on the project I learned a lot about how simple machines work and where. For an example we were having trouble coming up with a third simple machine so we decided to use a pulley to meet the standard. However we had lots of problems getting it to work and we were running out of time. So the morning of the day that we were to be tested we made an inclined plane and placed it over the front of the car. This acted as an air wedge and wind shield and also made it look much more attractive. The point is we found we were able to overcome problems and learn from them as well. - **Tim & Mark**

When this project was first given out, I thought that coming up with an idea for a machine was difficult. However, once I had my idea set up and my plan made, it was fun to make. I found it was really exciting when I got my machine to work. Overall, the machine was actually really simple to construct. - **Mari**

As I came closer to finishing my machine I realized that it wasn't an impossible task. As I came closer to finishing my machine, the activity became more and more enjoyable and when I finally finished, and the machine worked, I was very happy. - **Sheena**

That this kind of project is really fun to do. - **Ricardo**

3. What parts of this project did you find easy? What parts did you find difficult?

We found it easy to imagine what we could do, b ut it was difficult to realize if it were realistic. It was also very difficult to actually put together (in real life) what was in our heads, or in other words, actually make the machines. - **Linday & Sasha**

I found easy the planning of my machineand I found difficult finding an idea and building the machine. - **Tony**

We found getting started and thinking of an idea for a machine hard to do at first. Once we got started, we found it easier to accomplish our work. - **Leena & Samantha**

We found that cutting and measuring the cardboard was the easiest part. We also found that the elevator was the most difficult to make. - **Deani & Karisa**

Building the structures was easy, but acctuly geting them to move, pull, or drop somthing was alot harder. - **Amy**

The paper work was the easiest because it was just writing down what we wanted. Building the actual machine was hardest because we had to convert what we wrote down into a real object. - **Sharlet & Kandy**

There weren't many parts of this project that I found easy, but there is one thing that was easy, building the elevator. There were quite a few things that I found hard. Building the water whee, stabalizing the shaft, hooking up the pulley and getting the elevator to work. All these things took a lot of time. - **Sharon**

We found putting toghther the machine was easy, it's creating the machine that was hard. - **Vance & Cameron**

I found making the track was hard. - **Brian**

The easiest part of this project was the initial designed, but th hardest was having to find ways we could improve our original design. - **Katty & Anne**

We found that putting the motor and batteries together turned out to be pretty easy. The difficulties were getting the car to be stable and able to hold weight while actually moving. - **Johnny & Dave**

The whole idea of our project was simple but making it work was difficult. - **Lorisa & Lavana**

Getting the idea was easy, putting it together was the hard part. - **Andrea & Janesta**

Finding an idea was easy, but bringing it out was tough. - **Keith**

While working on the project I learned a lot about how simple machines work and where. For an example we were having trouble coming up with a third simple machine so we decided to use a pulley to meet the standard. However we had lots of problems getting it to work and we were running out of time. So the morning of the day that we were to be tested we made an inclined plane and placed it over the front of the car. This acted as an air wedge and wind shield and also made it look much more attractive. The point is we found we were able to overcome problems and learn from them as well. - **Tim & Mark**

While I was constructing my machine, I had to sometimes think of better ways of making my subsystems so they'd look attractive, or stay strong, or even function easier. Because we didn't have a really long time period to make our machines, I had to start recreating the other parts of it that were especially hard to make, so I could complete my machine in time. - **Mari**

I discovered that if I work hard and keep trying, it is possible to finish a seemingly hard project. I thougt that the building of the machine was fairly easy compared to planning the design of the machine. After I decided upon a procedure to build my machine, following the steps was easy. - **Sheena**

I found the easy part was to assemble the project. The hard part was perfecting it. - **Ricardo**

4. Did you find anything that was unexpected or surprising as you worked on this project? If so, please describe it.

We were surprised to see that the ramp and elevator wouldn't cooperate. The ramp was often not in the right position to perform the task of putting the marble into the elevator. We were expecting the other problems we ran into. - **Linday & Sasha**

Yes, when I used a lever and a cart (see second diagram), it did not worked because the lever got stuck between the axle of the cart and the cart. - **Tony**

We didn't think that building a machine would be as hard as it is. - **Leena & Samantha**

We didn't get any surprizes or unexpected actions when we were making our machine. - **Deani & Karisa**

Yes, a design is easier to draw than it is to make a machine and simple designes are the best for well working machines. - **Amy**

We were really surprised when the machine was finished and especially surprised when we tested it and found out it worked, because at first we were thinking "Oh no! One week to build a machine? We're never gonna finish." and " This is not going to work! We're gonna fail." Then we came up with a machine that works and we were really happy. - **Sharlet & Kandy**

At the begginning I had no after thoughts about getting the machine to work. Gradually, as I worked, the more I realized that it was going to be harder and harder to get it to work. That is the only thing that worried me. - **Sharon**

Nothing seemed surprizing, it just went the way we planned it. - **Vance & Cameron**

No. - **Brian**

No, we didn't. - **Katty & Anne**

Yes, we thought that the motor and the type of batteries that we used were going to make the car travel at a medium speed while carrying a load. But what we found out was the car still moved very slow and at times didn't move at all. - **Johnny & Dave**

We thought things were going to be easy to put together but they weren't as easy as they seemed. - **Lorisa & Lavana**

The ramp (toilet paper roll) got wet. That our cactus watering machine worked. - **Andrea & Janesta**

There was nothing very unexpected, except that it looks like a roller skate. - **Keith**

We didn't really find anything unexpected about the project but it did come as a surprise to me how a CO_2 cartridge works seeing that I had never used one before. - **Tim & Mark**

If we had an opportunity to make changes to our machines, I would take time to try and make it so that I could dispense the beans just by pressing on an object such as a button. I could try to make the machine bigger and stronger, and I would build it so that I have more room to hit the pendulum to get the machine working. - **Mari**

When I was planning my machine, I thought the force of one marble in the first wagon would be enough to lift the load that is the second wagon. However, the force of the marble was reduced because the string that was attached to the first wagon had to cross two pulleys before it lifted the second wagon. The pulleys reduced the force of the marble, so it was unable to lift the wagon. To solve this problem I had to place a 100g mass in the first wagon with the marble. - **Sheena**

Really there was nothing surprising. - **Ricardo**

5. What limitations did you encounter while doing this project? (e.g. limitations of time, energy, enthusiasm, materials, resources such as books or people and so on)

We didn't have enough time to call some candy stores and find the right size and weight of candy we needed. - **Linday & Sasha**

I encounter limitations of time and materials. - **Tony**

Because we found it hard getting started, time was a very big deal, and it seemed to get used up so quickly. - **Leena & Samantha**

My partner and I found that we had very little time to make and perfect our machine. We were both also very enthusiastic during this assignment. - **Deani & Karisa**

Yes, I thought I could have used another double (more time) to work on my machine. - **Amy**

One major problem was the limitation of time, we only had a week. Another limitation was the fact that we had so little knowledge about building a machine. Neither Kim nor I had ever built something with simple machines before. - **Sharlet & Kandy**

The only real limitations I had were time and materials. I built most of mine at home so I had a limited resource of materials. - **Sharon**

We found that we needed more time, I think our machine would be alot better if we ahd 1 extra week. - **Vance & Cameron**

I don't think I found any limitations. - **Brian**

The main limitations were the amount of time we had to do the machine and the materials. - **Katty & Anne**

We were very limited in time. While we were working on our project we came up with many ideas. When our first idea didn't work we decided to use some of the those ideas. But they didn't work either. When our last lunch hour came we used it and got to work right away and ended up finishing. - **Johnny & Dave**

At first, we spent hours planning and thinking what to do and that was very time-consuming. The stressful part was the building. Throughout the whole process of building, we were very enthusiastic. - **Lorisa & Lavana**

We didn't reach any limitations because if we came across a problem, we overcame the obstacle. - **Andrea & Janesta**

The time limits were large and a pain. - **Keith**

Our project went quite smoothly with only a few problems related to the third simple machine and the power source. We originally wanted to do a car powered by a rocket engine but we were not allowed to. So we had trouble thinking about what we would use so it would still go fast. We eventually used the CO_2 cartridge and it worked. - **Tim & Mark**

(no response) - **Mari**

I did not encounter any limitations in this project. I had all the materials and time that I needed. - **Sheena**

The only limitation I had was I did not have enough materials. - **Ricardo**

6. If you could start over, what changes would you make:
a. in your design?
b. in your planning process?

a) We would make our own elevator and
b) it would be a different design than the one we had, (it would possibly be made with an electric pulley), but we didn't know there were electric pulleys until we saw Elicia with one. If we made our own elevator, it would be much easier to make changes and improvements to it, whereas when it's already made, we discovered that it's difficult to make changes and improvements because we don't have the right materials. - **Linday & Sasha**

a) I would make my machine more simple,
b) I will do my planning process faster. - **Tony**

a) Our design would have probably looked better if we had more time.
b) We would have tried to work alot faster and maybe more seriously. - **Leena & Samantha**

a) My partner and I would have made a lever at the end of the inclined plain so the marble wouldn't go into the bag.
b) Kim would have wanted Deng to come in the group at the beginning of the machine. - **Deani & Karisa**

a) I would not ue pullys to take the fish cart up the ramp because they were unrelyable.
b) I would spend less time drawing pictures and diagrams of it and only draw one diagram, then start, also if I could I wouldn't use "Lego" because its not very strong. - **Amy**

a) We would paint our machine. The floor grounds would be green, like in a real golf course. We would also increase the width to add more decorations.
b) No changes. That part was perfect. - **Sharlet & Kandy**

a) If I could start over the changes in my deign would be to make the elevator lighter and have the water wheel spin easier (I would set the water wheel up in a different position).
b) I would plan ahead so I had all the right materials and make sure I had a water hose ready with lots of pressure. - **Sharon**

I would change how the design looks like, but I wouldn't change the process. - **Vance & Cameron**

a) I might change how I did my track.
b) I would take more time on my planning. - **Brian**

a) We'd make something that would catch the ball and it would be made of steel so that there wasn't a fear of it exploding.
b) We'd start building the machine earlier than we did. - **Katty & Anne**

a) We would probably start off by using one of our other ideas and work further into it. We would change the design of the model and try making the motor more powerful and the batteries more powerful.
b) We would try planning it more differentlyand give ourselves more time to plan out our idea so we could be assured a positive project. - **Johnny & Dave**

a) The design would definetly stay the same because of its originality. We like that!
b) The planning took a long time but it would probably take less time if we were to do it again because we would know what we were doing! - **Lorisa & Lavana**

a) Oh, the car, we could have an arm going up to get the golfballs into motion.
b) To start earlier on the whole process (and on the overview). - **Andrea & Janesta**

To tell you the truth, there is nothing I would change (except have the axel aim properly). - **Keith**

If I had the chance to do this project again I would try to make the car lighter and more streamlined. I would also like to get better wheels so it would have less resistance. - **Tim & Mark**

If I were to design another machine, I would have an idea similar to the bean dispenser. I might make it and extended machine with more subsystems to go through to complete the task. Or, I can do the opposite, and take out some subsystems and experiment with motors instead of levers and ramps. I could make the bean dispenser work with batteries. Otherwie, I would just make up a new task and construct a new machine. - **Mari**

I would change my design by making the ramp a bit more steep. Then it would take less force to lift the second wagon. I would change my planning process by writing down my procedure. This would make it easier to finish my machine in a shorter time period. - **Sheena**

(a) and (b) I am happy with this design. - **Ricardo**

7. How well did you meet your own expectations in doing this project?

We think we met our expectations very well. We made the marble travel a total distance of at least 2 meters. The goal we set for ourselves was 1 1/2 meters for the total distance the marble should travel. We also decided that we wouldn't have the candy break, and if it did, we would soften the landings, etc. We did try it with candy a few times, and it didn't break, so we also met this expectation. Also, (we didn't write this down) but we wanted the machine to look nice. We thought it looked quite nice, it wasn't unattractive. - **Linday & Sasha**

I met them very good. - **Tony**

We met our expectations fairly well. The only thing we expected was that it would be easier. - **Leena & Samantha**

We thought we meet all of our expectations while building our machine. - **Deani & Karisa**

I met all of them. Exept my original expectations changed because I dicided to not use a real fish. - **Amy**

Very well. Not only did we finish our machine in timebut we made it look nice and had an extra type of simple machine. - **Sharlet & Kandy**

I think I met all of my expectations and expanded on them. - **Sharon**

We met our gaol and improved on our machine as we went. - **Vance & Cameron**

I feel I did quite well. And I met my expectations well. - **Brian**

I think we were both dissapointed at the fact that the project didn't do its job when we were showing it to the class. But otherwise we enjoyed doing the project. - **Katty & Anne**

We did not accomplish as much as we set out to do. - **Johnny & Dave**

Our expectations wer met fully because we wanted something different, yet simple. The machine worked and that is the important part. - **Lorisa & Lavana**

We think we did well and we and we think we met the expectations. - **Andrea & Janesta**

I met them perfectly, I worked well throughout the project. - **Keith**

I was quite happy with how the project worked out. We made a good looking and successful car that worked three fourths of the times moving far and fast. - **Tim & Mark**

While doing this experiment, I think I did quite well in staying on task and meeting the expectations. I discovered that building and constructing machines was fun, even if I had to think about the characteristics of simple machines and energy converting many times. - **Mari**

I planned to make my machine more complicated than it ended up being. But I basically wanted to build a machine that worked, and since it did, I met my expectations fairly well. - **Sheena**

I met them all, exept with the pulley. - **Ricardo**

8. Did you have an opportunity to discuss your project with Mr. MacDonald? How did those conversations affect the development of your project?

A few times we asked him to help us with a few problems we were having (we asked him for a new elastic and some batteries) but it didn't really have an affect on the development of our project. - **Linday & Sasha**

Yes, he helped me a lot with the planning and building of my machine. - **Tony**

We talked to Mr. MacDonald and he helped us gather some ideas and to get started. - **Leena & Samantha**

We had no chance to talk to Leo except during the interview. - **Deani & Karisa**

Yes, I did. He gave me some suggestions that I used and he also got me some materials that helped my machine to be stoger. - **Amy**

Yes, we talked to him alot, though he liked our idea and didn't add any changes for us. - **Sharlet & Kandy**

I did discuss my project with Leo but it didn't affect my project. He did give me some ideas and thoughts but I didn't expand upon them. - **Sharon**

Yes, we did have an oppurtunity to discuss our project with Mr. MacDonald, but it didn't help, because we talked to him after we did our project. - **Vance & Cameron**

I only talk to him after my project was done so it didn't have an effect. - **Brian**

No, we didn't. - **Katty & Anne**

Yes, we did discuss our project with Mr. MacDonald. The conversations we had and the ideas he gave were all a positive influence towards our machine. The motor we used was leant to us by Mr. MacDonald. He also gave us good suggestions for our project. - **Johnny & Dave**

Leo helped us a lot. He provided some of the materials and plus he showed a great interest in helping us. He helped us improve on our project by suggesting new ideas and giving compliments. Thank you, Leo! - **Lorisa & Lavana**

Yes. He gave us help and he gave us some helpful material. - **Andrea & Janesta**

I spoke with him on several occasions and he sort off directed me onto the right path. - **Keith**

A very big help was Leo MacDonald. Almost every day we talked to him and got different ideas about how to make parts of our machine work. He gave some ideas on how to use the pulley as a guide line and also helped drill holes in our rocket tube for the engine stopper. - **Tim & Mark**

When I discussed my project with Mr. MacDonald, we talked about what I think of my completed machine or what did I like best about it, most of which I have answered in the paragraphs above. - **Mari**

Discussing my project with Leo MacDonald didn't really influence my decisions in this case, but he taught me how to saw, and that helped a great deal in the construction of my machine. - **Sheena**

I did not really need much help on my project. - **Ricardo**

9. If you worked with another person, describe how the two of you shared the tasks of designing and building this machine. What portion of the work was done by each person? Was the division of labor or sharing of responsibility equal?

We think that the amount of work each of us did was very equal. We both brought the materials, both 'gave and took' our ideas, both worked hard for the full amount of time we had, and both of us were always looking for problems and trying to find solutions. - **Linday & Sasha**

We shared our tasks equally and each did a little of everything. - **Leena & Samantha**

We did equal amounts of work. I think since Kim made the original design Dena did most of the paperwork, but we both did equal amounts of building the machine. - **Deani & Karisa**

Well, the two of us are kind of different. Since Scarlett worried so much, she kind of went ahead and thought of most of it, though Kim thought of how to incorporate most of the machines. Also, since she's the detailed one, she did most of the paper work, but Kim helped and put together most of the machine. And since Kim was so shy, Scarlett usually had to explain the machine and ideas to Mr. MacDonald. - **Sharlet & Kandy**

We both did the same amount of work in each part of the machine. - **Vance & Cameron**

The work was equally divided between us. we both shared our half of the responsibility well. - **Katty & Anne**

Dave and Johnny (me) worked very co-operatively. We tried to split the work in half and did a good job of it. Dave did most of the work on the project while Johnny (me) did most of the writing. - **Johnny & Dave**

Sarah and I both did the same amount of work. The same effort and time was put into our machine. She provided the music stand while I taped the dallowing together. We kept the machine at her house but ... (ends abruptly). - **Lorisa & Lavana**

I worked with Anthea, and we built the pendulum support. Anthea built it and I supplied some useful ideas. - **Andrea & Janesta**

Our group, I thought, did a good job of splitting the work. We both did our share. Mike brought the CONSTRUCTS which we made the car out from and I brought the rocket tube and the CO_2 cartridges that powered the car. For this final ANALYSIS I am doing all of part C and half of part B, Mike is doing the rest. - **Tim & Mark**

I didn't work in a group. - **Sharon, Brian, Amy, Tony, Keith, Mari, Sheena, Ricardo**

The Mousetrap Car Project

An exhilarating Eggsperience

Overview

The task is to design and construct a vehicle, powered only by the energy received from a given mouse trap, which will travel a 4 meter course in the shortest time. The vehicle is to carry a raw egg which must be undamaged at the end of the race.

Rules

1. The vehicle may be constructed out of any material and be of any size but must be built by the students and carry its motive source and passenger (mouse trap and egg) with it over the entire course.
2. All of the energy used to propel the vehicle must be provided by the energy received from the standard mouse trap supplied.
3. The mouse trap will be provided to each group of students prior to the event and must be an integral part of the vehicle design! (ie. NO replacement mouse traps allowed.)
4. The vehicle must not be given an initial impulse (push). There must be no external guidance at the start nor during the race, and the egg must remain undamaged at the end of the race.
5. The vehicle must start with the operation of a mechanical trigger which is initiated by the pull on a 1.00 m length of string! A race will be over for any vehicle which does not complete the course, or stops and will not self start.

Testing Conditions

The vehicles will be tested individually over the 4 meter course. The time required for each vehicle to complete the course will be taken be each of two judges and recorded. Each vehicle will be allowed two runs with the best time being used to determine final standings.

Judging

1. A maximum of 30 points will be awarded to the vehicle completing the 4 meter course in the shortest time with an undamaged egg. Each vehicle will be allowed two runs and the best time will be employed in determining points. Other points are awarded as follows:

1st quartile	2nd quartile	3rd quartile	4th quartile
28	25	23	20

2. Stopwatches will be used to determine the time required by each vehicle to complete the course.
3. Vehicles will also be judged for a maximum of 5 points for the aesthetics of their design, and a maximum of 5 points for producing a working prototype!

Report on The Mousetrap Powered Car Project

Andrew, Ken, Allana, Lillian (written by Andrew)

5

When we were first faced with the problem of designing this car we had some immediate ideas. The two most practical/popular were to:
1. extend the arm of the mousetrap and use that to drive a system of gears connected to the wheels.
2. extend the arm of the mousetrap and tie a string to it. The string would then be wrapped around the axle and when the mousetrap was sprung the spring would be pulled and the wheels would turn.

In addition to these basic ideas for propulsion we came up with a few basic principles which we would apply when building the car.

1. We decided that the wheels should have a large circumference so that they would not have to turn as many times to cover 4 meters.

2. We decided that the car should be constructed out of materials as light in weight as possible so that the energy required to get the car started is less.

In the end we chose design number one as the one that we would construct.

As Christmas holidays approached the group (Allana, Andrew, and Ken) decided to meet at Ken's house to construct the car. I (Andrew) was given the task of finding the materials that we would need to construct the car. To my dismay there were no places in the city which sold gears of the required size. I then phoned up the group members and we decided that we would still meet at Ken's house to come up with a new design. Unfortunately, Allana was not able to make it to the meeting so Ken and I decided that we would construct design number two and see if it would work.

A few days later Ken and I began to construct the car. The design started well but our first major problem was the clips that we were using to fasten the axles to the car - they were designed to hold the wire in place without allowing it to turn. Evidently the amount of friction caused by this would be too great to overcome so we solved the problem by gluing the clip around another larger wire so that when the glue was dry and the large wire removed there would be enough space for the axle to turn freely. The construction continued on without a hitch.

Our next major problem was encountered on prototype day. Our car did not even come close to the required distance. We reasoned that this was because the string was not wrapped around the axle directly but around a plastic collar. Because the collar and the axle turned at the same rate and the collar had a circumference a great deal larger than the axle we decided that if we removed the collar the problem would be solved. It was.

Over the next week finishing touches were added to the car. Various arm sizes were tested to see if they affected the performance of the car. We took the most effective arm and put it on a brand new mousetrap and now we have a car!

APPENDIX C

Selected Interviews and Conversation

Complete Transcript of Dan's and Tristen's Paper Towels Investigation

Leo: So the question at hand then is this one (points to index card). OK? Which kind of paper towel holds the most water?. Are there any questions you would like to ask about any of this material? I guess this is all stuff you have seen before?

Dan: Well, these (points to beakers) are plastic. Because we've got the glass ones at school but we don't have the glass ones for very long at a time because things happen to them. Not by us or anything because we would never do anything like that.

Tristen: OK.

Leo: Well, would you like to get started?

Dan: Sure. So are we supposed to figure out how to do this ourselves? We're supposed to figure out the experiment?

Leo: Yeah, you are pretty well on your own from here on in. You can ask questions if you like.

Tristen: OK, can we decide what level is totally wet? Like, sort of saturated?

Leo: Well, I'll let you think about those questions. You have a lot of freedom here in terms of what you decide to do.

Dan: So the question is: 'which kind of paper holds the most water?' I think this (picks up large tray) is going to be fairly major because we have to, I think, take a sheet of it and sort of lay it down there and then, maybe somehow, get it all wet ... pull it out and measure it to find out how much it weighs. If we can remember ... if we can get the temperature of the water to be right so that it's ... like, it's what?... three degrees Celsius and then it's one gram is one milliliter?

Tristen: Yeah, something like that. Yeah, we could do it that way if we took the weight of the paper towel and then weighed the entire thing when it was wet.

Dan: Yeah, then we could find out what the weight was ... what the mass was ... and finding out what the mass of it was we could figure out how much water we were thinking of here. That's one way.

Tristen: Hmm, yeah. That's a way we could do it probably.

Dan: So this (points at "Cusinart" balance scale) is the best one to use because then we can stick it in here and find out how much it weighs.

Tristen: It's pretty inaccurate there. There may not be a lot of weight there.

Dan: Maybe we could use a whole bunch of sheets of the same kind. Like six sheets or something and fold them all like this (moves his hands above tray to indicate stacking).

Tristen: Yeah, as long as they're equal.

Heidi: There's your papers for recording your results.

Dan: Do we have to fill out what our procedure was and stuff too?

Heidi: You can do whatever you like. The answer to that is if you want to fine, if you don't then that is also fine. You can record it any way you like.

Dan: OK, let's just make sure that these are all the same size. OK, first thing. So these things aren't all the same size. So that has to be constant. If they're all the same and that's constant then we can ... (places towels top of each other to test their fit for size) ... No, this one goes off a little bit here, a centimeter.

Tristen: OK, so put the other one on top (the pink one) so we know our edge.

Dan: So maybe we'll try it. We'll do this and see, sort of, what the results look like. See if it sort of holds true. So are we going to try taking four sheets of each one so that they're all the same size? So that we can have more discernible results.

Tristen: Well, for example, taking this next weight to see if you can even measure on the scale. Because if they don't measure on the scale then we can't test it ... you know ... it's worthless.

Dan: Well it's got to weigh something.

Tristen: Yeah it's got to weigh something, but does the scale measure? ... is the problem.

(Dan places one of the towels on the beam scale)

Dan: Actually it does. It weighs .... yeah ... OK, it weighs 2.325 grams.

Tristen: OK, so I should write that on the sheet.

Dan: Yeah, so the pink one is 2.325.

Tristen: OK.

Dan: OK, so now we got to cut the rest of them down to size because that has to stay constant.

Dan: Because one variable is the ...

Tristen: Amount of water.

Dan: No, the kind of towel and the responding variable is ...

Tristen: Amount of water.

Dan: Yeah, OK. So let's get these (towels) lined up and slice them up. Just be careful so that we don't get frayed edges.

(Dan holds stack of paper while Tristen cuts with scissors)

Dan: OK, so this one was 2.325. So the brown is ... I hate these scales ... the brown is ... 2.1. Now, the white is 2.45. OK, so I guess we would probably have a more readable result if they were ... (Tristen sits and records on paper as Dan works at the scales)

Dan: I don't think we should use this one because we can only go in ten gram units and we already got that down to ... well, I don't know ... four digits or something there.

Tristen: Well, yeah ... this is pretty accurate ... fairly accurate there.

Dan: Well I mean, if we can just use one of these beakers here ... find out how much it weighs and then just take the thing ... if we can remove it with the old chopstick here ... just lift it up here ... drop it in here... (Dan pantomimes the required movements as he speaks)

Tristen: Weigh the entire thing.

Dan: Weigh the entire thing and then minus this and the paper towel ... find out how much the water weighs ... and then we have ...

Tristen: That should be fairly exact.

Dan: So, are you going to want us to go into how much the water weighs in terms of how much there is?

Heidi: You can do whatever you want. It's your show. It's all under your direction.

Dan: So we don't have a thermometer so we can't check the ...

Tristen: Water temperature. No.

Dan: We know it's cold water ... it's cold water ... it's going to be close enough ... I mean its going to be like that much ... I mean it's not like the outcome of the world is hinging on this experiment ... not like that we have no respect or anything ... no this is ... all right so how many do you want to do ... four?

Tristen: Hmm ... four should be enough weight. The water will actually be readable.

Dan: So do we want to paste them all together? Because I think this thing ... we'll be able to tell ... let's try one and see how much we are talking about here. So I think what we can do is if we can fill this tray with water and then just dip it in ... pull it out ... stick it in the thing. OK, so let's find out. Is this (plastic beaker) the biggest one?

(Dan weighs the beaker while Tristen waits to record the result)

Dan: I've always hated these things. (referring to the scale)

Tristen: Is this (points at beaker on scale) labeled "water"?

Dan: Yeah. OK, wait a second. They should make these things (scale) remote control so you could just go whoop whoo.

Tristen: Pretty complicated.

Dan: We'll do that in science and tech next year. The reason I want to take science and tech is because I think he'll let us build the blimp. Seventy-six point four. OK, so that's how much this weighs. So what should we go with? Should we go with this one? Just sort of see ... because ... no, we should go with the lightest one which will be ... that's the brown ... or the white?

Tristen: Yeah, the brown one is the lightest.

Dan: OK, so I suppose we should do a hypothesis first. Ahh, the heaviest paper will hold the most water.

Tristen: That makes sense.

Dan: Yeah, OK.

Tristen: So that's the white paper.

Dan: OK, so this guy (white towel) is the heaviest. So we hypothesize that the white paper will hold the most water because it's the heaviest and we think that ...

(Dan has the pink towel in hand and is about to put it into the tray)

Tristen: The brown is the lightest sheet Dan. (he seems to want to start with the brown sheet)

Dan: Well I think that this one (pink towel) will hold the least because I mean its all ... I mean you can see through it and everything ... and its got sort of all these little bumps on it. So its sort of corrugated and ... I don't know.

Dan: So what do we want to do? So do we just sort of (places pink towel in tray).

(Dan turns on the water tap and prepares to fill a small beaker)

Dan: All right, that's pretty cold. It's not frozen or anything. So I say we should put the same amount in here each time jut to keep that the same.

Tristen: Yeah, probably.

Dan: So, what? 500 milliliters?

Tristen: Umm ... yeah ... and if it can't hold that much then ...

Dan: Try it out and start again. We got paper towels. (pours about 500 ml of water in the tray)

Dan: Yeah, that's just right. OK, so we're going to go with this one?

Tristen: The brown one because its the lightest, remember?

Dan: So we're not actually taking results right now because we're just seeing if this is going to work. (Dan puts a brown towel in the tray) ... and once its all completely the same color then we can ... (referring to the apparent change in color once a towel becomes wet)

Dan: So do we pull it out and slip the thing under as fast as possible or should we use this to see how long it sits there? (Dan pantomimes the movements as he speaks)

Tristen: Probably, because there's probably a lot of excess water on the bottom ... and it will suck some of this up with it.

Dan: So let's try to figure out how this thing works. OK, that makes sense. Umm ... OK, so maybe if one of us lifts it out and the other is holding this and this and as soon as it goes two seconds ... and just stick it in there right ... and we can be pretty close [together]. (Dan pantomimes the movements again, this time including the stopwatch)

Tristen: Umm ... we should give it probably a bit more than two seconds ... so you don't have to be so exact.

Dan: Five seconds? Five seconds so that we're not ...

Tristen: Yeah.

Dan: OK. Because if that's constant ... if everything else is constant we should get an accurate result. Our responding variable should be accurate.

Tristen: Dan? Is it this button?

Dan: Umm ... yeah.

Tristen: OK. As soon as you get it out of the water.

Dan: So, five seconds?

Tristen: Yeah.

(Dan attempts to pick up the wet towel in the tray by sticking the wooden chopstick underneath)

Dan: I want to try and keep it flat like this. (changes his mind about using the chopstick)

Tristen: Use this thing. (points to the ruler)

Dan: Use the ruler. (Dan begins to use the ruler but stops suddenly) It's going to break. We found out in science at our school that paper towel is pretty cheap so ...

Dan: We should put more water in. That's what we should do so that its floating higher.

Dan: Don't ... don't try that. (Tristen has tried to pick up the towel with his fingers)

Tristen: Take it from both sides and it might work. (Tristen pantomimes with both hands)

Dan: Well, lets get some more water in there anyway. Its not going to make any difference now. As long as its the same amount then we don't have to worry. But if it's a bit higher in there then it might be a bit easier to work with.

Tristen: As long as it stays in there.

Dan: So we'll go with the liter? (Dan pours another 500 ml in the tray). OK, so just write that down so that we can ...

Dan: Should we record our constants while we're going here? Just to keep everything ...

Tristen: Well, we pretty well know what they are don't we? Like we got to keep the same amount of water in there.

Dan: Same size paper towel.

Tristen: Same size ... yup.

Dan: Same time from when it comes out of the water to when it goes into the beaker.

Tristen: And same ... like this thing has to be the same.

Dan: OK, once its in here we can just jam it all in there (large beaker) because the water will stay the same in there ... then we can minus this [weight of towel] ... this [weight of large beaker] ... and then that will give us how much of the mass of the water we have in there (in the beaker) ... and then we don't have to figure out how many milliliters there are because we'll know from the mass which one had the most. Pretty smart.

Dan: Wheee! (Dan adds water to the tray, towel is still in there)

(Dan is staring intently at the towel in the tray)

Dan: It's not floating anymore. (towel seems to have sunk to the bottom of the tray)

Tristen: Well, part of it isn't. OK, but there's a big ... this edge is way off. (towel is skewed in tray)

Dan: OK, partially this either isn't flat or the table isn't flat. But that shouldn't be too much of a problem. Yeah, OK this will do now.

Tristen: OK, I'll wait until its all out of the water.

Dan: OK, whatever. One ... two ... three ... (picks wet towel up with chopstick)

Tristen: Don't fling it. Wait, we have to time it. OK, now.

Dan: Oh, oh. (towel is stuck to the wooden chopstick)

Tristen: OK, well we can break it. It doesn't matter as long as we get it off.

Dan: Well, we can just slide it off. OK. Now, maybe we shouldn't give it any time for that because I think we lost most of the water there.

Tristen: OK, next time no time.

Dan: See it's nothing. There's like two grams of water in there ... and because we can't be sure that we're going whoop ... right in there, exactly the same ... we should just ... as soon as it comes out ... slip it in somehow. Because if this is the lightest one ...

Tristen: Yup.

Dan: OK, we should keep a sample of this [brown towel]. OK, this one is always the same size. We're just cutting the other ones [pink and white] down.

Tristen: Right, because that's the smallest one.

Dan: OK, well we should chuck this.

Tristen: Right.

Dan: Forget this one. OK, that's just our one to see if this will work.

Tristen: We should test it again ... to make sure.

Dan: Now, we should dry this out each time so that there's no water left over in there and no paper towel or nothing ... you know.

Tristen: OK, so do you want to cut some more of these down and see how we can get ...

Dan: OK, so three more of these ... or four more these.

Tristen: Oh yeah, right. Three more of everything else.

Dan: If one rips, we don't use it because then it will be messed up. That's one of the reasons we could use sort of four of them. We could actually ... oh no ... that wouldn't work if we were cutting them down. If we left them all attached like this and then they were all folded up. But that wouldn't work.

Tristen: The sides would screw up.

Dan: Actually this one is ripped but we can cut this one down. Industrial size sheets of paper towel.

Dan: So can you see what we're doing past all of this stuff? (Dan looks up to address us)

Heidi: Yeah.

Dan: How are we doing?

Heidi: You are doing just great.

Dan: Well, it partially comes from our teachers never-ending sort of ...

Tristen: Remember in science?

Dan: Well, yeah. That's our science teacher.

Tristen: In grade six though.

Dan: What? Madame B.?

Tristen: Yeah, like we took the same thing every time. We took ... what? ... battery unit.

Dan: Battery unit.

Tristen: Yeah, we took the battery unit, like twelve times.

(Dan and Tristen are cutting several sheets of each towel down to a common size)

Dan: But we learned about the ahh ... oh what ... the ahh ... the experimental method ... or whatever ... procedure or whatever. Well, you know, you have your problem, question, hypothesis, materials ... everything like that ... and you have your inference and conclusion and stuff. But they pounded that into us to the extent that I dream about it at night. (Heidi and I laugh). But we did science fair too, so ... and we came second last year ... total fluke. We're going again this year ... whenever it is ... I don't know ... I didn't pay attention.

Dan: So will we get to know sort of how smart we were? How we did on this? If we did what you expected or what other people had done? Will we get to find that out after?

Heidi&Leo: Yeah, we'll talk.

(Tristen continues cutting, Dan puts a pink towel in the tray of water)

Dan: There's got to be a better way to pull these things out. Holy! It went whoop! Expando-contracto! Oh, that's why it should be sort of like this. You know, like this way, because it expanded.

Tristen: See how much water there is. Just sort of ...

Dan: There isn't a heck of a lot. That's why we go with four right ... and we lay them all in there at the same time, right ... stick them in there ... pull them out ... jam in here (large beaker) and ... [puts beaker on scales].

Tristen: Actually they should hold enough water to be measurable.

Dan: Uh huh. All right, so lets see what happens to these things when we stick them in there. Once they're, sort of, reaction. See if they all stretch like that. Because maybe we should be taking that into account somehow.

Tristen: Well, if they stretch that's sort of the design though.

(Dan tries wetting a brown towel in the tray of water)

Dan: Yeah, I guess so. I guess they all do that to some extent. So we got to make sure that they all stay floating on the surface and don't submerge ... or we can sort of sink sections of it ... like this (pushes towel down under water with ruler) ... because we want to find out the maximum amount that this thing could possibly be holding. Right?

Tristen: Yeah, but that's water on the surface, really ... that it's holding ... it's not even really there sort of ... you know?

Dan: Yeah, then we run into this problem of getting it out. Right? (lifts wet brown towel out with a chopstick) Whee!

Tristen: OK, these are all cut so ...

Dan: Yeah, OK. We'll have to go with multiple sheets. Otherwise we won't get anything from this. We should make sure that there's always ... but that's not going to make any difference is it?

Tristen: How much water is in there?

Dan: Yeah. As long as its above the ... as long as its not touching the ground.

Tristen: The only reason why you'd want a certain amount of water is just to make sure that it floats.

Dan: So that's not going to make any difference ... because we'll have to redo the pan each time. I mean, we could do that but that's not going to make any difference. How much water is in the pan is not going to make any difference. Let's fill this guy (tray) up a little bit more so we have lots of ... We got to make sure to towel this thing out each time after a test you know.

(Dan adds an extra 500 ml of water to the tray)

Tristen: That's probably enough.

Dan: OK, you want to towel this out? OK, so we got four here. One, two, three, four.

Dan: So, which one did we predict was going to hold the most? This one. Right?

Tristen: Yeah, the white one.

Dan: So we'll use this one when we're cleaning out the beaker.

Tristen: OK, I'll put it over here.

(counts out three groups of four sheets)

Dan: OK, so there were paper clips here. Right? Should we clip them together? ... or is that ...?

Tristen: That's just more weight we have to subtract into it ... is the only problem ... because I mean, the weight of a paper clip ... and then we have to weigh that and subtract that out. Think so? Well, we'll weigh four paper clips. See how much they weigh. You know?

(Dan seems concerned that expansion during wetting will cause tearing of the paper if paper clips are present).

Dan: Yeah, but when this thing ... because they go in here they can expand. Right? They're going to rip or something if they've got those things on them. Right?

Tristen: Umm ... they could break right through. Yup. See what happens.

Dan: Well, lets put it on one sheet or something ... or two sheets. OK, we know these guys both expand so ...

Tristen: I don't think we're going to need paper clips.

Dan: Probably don't.

Tristen: Because the water ... it (towels) can hold lots.

(Dan attaches two towels with paper clips and puts them in the tray of water)

Tristen: That thing holds a lot more water with two. (first time observing multiple towels)

Dan: It sinks the corners too. It doesn't rip them but God knows what it would do to that pink stuff because that just goes whoop (Dan moves his hands in a spreading motion). OK, so we won't use paper clips then?

Tristen: no.

Dan: OK, we should probably figure out something else because this ... Oh I don't know.

Tristen: I mean the water isn't going anywhere.

Dan: RC(??) is easier to get off than this stuff. I'll try not to cut to cut your chopstick in half. (Dan has removed the chopstick and is looking closely at the towel inside the beaker, he shakes it around a bit)

Dan: I don't think we need the paper clips! OK, I'll just take them off here.

Tristen: Should I put this in here right now? (next stack of towels)

Dan: No, just hold on here. (Dan squeezes out water from the wet towel and discards it. Then he observes the remaining water in the beaker). So, that's how much ... sort of.

Tristen: Yeah, water.

Dan: Yeah, so that's much easier to ... and with four ... I mean, we'll be able to know exactly. We should do a couple of tests of each ... you know, to make sure ... like one four and then another. Just so that we can see exactly what ...

Tristen: What do you mean like a couple of fours? Test four of them?

Dan: No. Like test four. Right? Boop! ... and test another four ... boop! ... and make sure. (Dan moves his hands as he speaks to illustrate his ideas)

Tristen: You mean test four of the same type.

Dan: Yeah, do that twice. Yeah.

Tristen: Well, put those in and so we'll do the first ones and I'll cut the next ones.

Dan: OK, I just want to figure out a table here ... so that we can ...

Tristen: Here, I'll just get these prepared. (Tristen prepares towels in stacks of four while Dan records results on the sheets).

Dan: What? The next ones?

Tristen: Yeah.

Dan: OK, I didn't put a title on our table but I don't think we'll lose marks.

Dan: So, should I dump the first of these in?

Tristen: Yup. Oh, we should empty that out too ... the water thing. (large beaker still contains water)

Dan: Oh yeah. OK, I'll wipe it out.

Dan: Wheeee! (Dan plays with the beaker by pretending to "land" it (airplane style) on the scales)

(Dan takes the stack of brown towels and prepares to put them in the tray of water)

Dan: Ready? Do you want to observe this?

Tristen: Yeah, I'll ...

Dan: All right, this is going to take a while. (Dan motions with his hands in a circular motion as if implore the towels to wet faster).

Tristen: Push it down a bit.

Dan: I think we should leave it unassisted to do this. We made sure that they all rolled the same way because they all had a little bit of a curve. We made sure that stayed the same.

(After several seconds, Dan picks the wet towel out of the tray, dumps it into the large beaker and places this on the scales)

Dan: Yeah, OK. Ahh! Results ... over two hundred grams ... two hundred and twenty eight point five ...

(Dan sits down to record results, Tristen continues to prepare more towels)

Dan: So, 228.5 grams minus 76.4 minus ...

Tristen: Calculator. (Tristen gives Dan a calculator)

Dan: Thanks ... so this is the brown ... 2.1 minus bracket ... times four ... close bracket ... equals ...

Tristen: Remember in LA when we were supposed to ... when we were supposed to say the sentences ... with all the punctuation?

Dan: One hundred forty three point seven.

Tristen: What? grams of water?

Dan: Uh huh, of water, yeah ... and then we can divide that by four again or as long as we're always going with four they'll stay the same and then we'll be able to compare them after.

(Dan places a stack of four pink towels into the tray)

Tristen: OK, these are all cut. (Tristen has finished preparing towels)

Dan: That was quick. (referring to the wetting action of the pink towels)

Dan: See, this thing (points to the scale) doesn't go to point five or point two-five grams. I just have a keen eye for these things so I can tell.

Tristen: Just guess, right?

Dan: No. Well, you can see, right? If it's half or whatever, you know.

Dan: It sunk. The bottom one. (Dan can't get the chopstick under the stack of pink towels).

Tristen: Here, use the ruler.

Dan slides the ruler under the wet towels in the tray, dumps them into the beaker and places it on the scales. The scales have been left at the previous setting - used for the brown towels - and Tristen notices the scale tipping to indicate that the new weight is heavier)

Tristen: More! (He smiles and catches Dan's eye)

Dan: The brown one was the lightest paper, right? ... so it was ... so we predicted it would hold the least right? ... or no, we predicted this one would hold the least but that's not important ... we predicted that the white one would hold the most.

Tristen: Right.

Dan: Actually this one holds less by a couple of grams.

Dan: I read the scale wrong before ... no I didn't ... you didn't hear that ... I read it right ... yeah ... ahh ... two twenty seven point five ... yeah, OK I think I screwed up measuring the scale ...

Tristen: In what one?

Dan: The first one. Because I had messed up reading these numbers in between. Because those aren't decimal. I don't know what I was thinking.

Tristen: You mean when you were reading the scale on the first test.

Dan: Yeah, well that was the pink ... no, the brown ... (Dan looks at the sheet) and I reported it wrong on the table.

Dan: So we'll disallow test number one. (Dan crosses out the results recorded on paper)

(Dan remeasures each towel and satisfies himself that he can measure the weight properly. Tristen uses the time to reorganize the stacks of towels. Dan records his measurements and turns his attention back to the tray of water).

Dan: So, OK. I think we have to figure out a better method of getting these things out of here because they're dropping a lot of water.

Tristen: Uh huh. We don't have a better way to do it though.

Dan: Maybe if we could sort of stick it in the pan. Right? (puts a small piece of towel in the tray) Whooo! Then pour all the water out of the pan but the thing will still be wet. Right? Because we minus off the ...

Tristen: Yeah, you could do it that way.

Dan: Because then we wouldn't get any spillage and it would be the same for all of them because we are definitely when we pull it out it's going "bull-a-lull-a-loop" ... and we can't be sure that we're losing the same amount from each one because they're holding different amounts anyway and whether its a percentage or whatever.

Tristen: OK, yeah. We could do it that way. Just ... then we should put lots of water in because then we don't have to peel it out.

Dan: So should we do that? I think that will work best.

Tristen: I vote that we don't transfer. We just measure the ... we empty this out. Right? It's got the paper towels here.

Dan: Then we just stick it right on here. Yeah. OK, so we have to empty this out and measure it. We should probably do that at the sink there. (gingerly picks up the tray and puts it down quickly)

Tristen: That's going to be a challenge to carry.

Dan: There are so many different ways you could do this. (referring to their experimental procedure)

Tristen: Hmm. There's a lot of water in here.

Dan: But you see we could do it in there and then we could also do the pour out method ... and then measure it in the pan there like that ... or ... well, that would be too much margin ...

Tristen: That would be the same margin for error.

Dan: There's got to be an easier way to empty this out.

Tristen: Well, if there's less water it will be easier to empty but right now I don't want to carry it to there because it's going to spill.

Dan: OK (clears beakers and other equipment away from small sink at the center of work table)

Tristen: Because the pan is, you know. Yeah, if we move everything we can empty most of it.

(Dan tips tray at one corner to empty it, then picks it up and notices the beads of water remaining on the trays Teflon surface)

Dan: OK, now we get this right but it should be ... we should get this (beads of water) on all of them so it shouldn't matter. Right?

Tristen: Well, we could dry it. All right. That's not enough to measure anyway.

Dan: So we should wipe the bottom off of this. Just wipe it off. I want to keep these on here and measure them too.

Tristen: OK, they'll be there every time.

Dan: But by like three grams ... or not even that.

Tristen: They'll not even measure Dan.

Dan: Right, assuming of course that we can read this [scales].

Tristen: It won't weigh like five tons.

(Dan weighs the partially dry tray)

Dan: OK, finish measuring this maybe (waits several seconds for scale to stop oscillating). OK, four hundred and eighty-seven point eight. I read it right.

Tristen: OK

Dan: So I think we should just go this way. I was thinking we could have the same amount of water in there, then put the thing in and then drain it out into a beaker and find out how much water was left over but that would be stupid because we've got this figured out. It should work.

Tristen: Yeah

Dan: That's further research.

(Dan adds 500 ml of water to the tray and notices that it does not have a consistent depth throughout the tray)

Dan: OK, so that's not enough. I'm trying to put the same amount in. I'm trying to figure out whether it's the table or the pan. (looks closely at the tray as he rotates it through one full turn)

Tristen: It's probably the pan.

Dan: It's the pan ... the pan.

(Dan places a stack of pink towels into the tray of water)

Dan: OK, so we've got the roll part down. OK, so now we've got to get all the water out of here.

Tristen: Except for what's on the ... in the ...

Dan: Yeah, except for what's in the sheet.

(Dan slowly tips the tray up at one corner draining the water into the sink. The wet towel remains untouched and undisturbed in the tray, stuck flat to the bottom. Dan holds this up at a steep angle and observes the wet towel to see if any more water will drip out.)

Dan: So, there's some coming out of the sheet ... no, OK. So that's how much it held. Right?

Tristen: uh huh

Dan: It stayed with it.

(The two boys seem to relax noticeably and talk about a school Marine Biology trip. Dan is weighing the tray and wet towel on the scales and Tristen is sitting down waiting to record the results)

Dan: OK, five hundred and seventy point one. So, hold on (Dan takes over the recording from Tristen). So, 570.1 grams minus 489.8 minus the weight of the paper which for the pink was two point four times four ... Bracket two point four times four ... equals ... so that's .... 9.6.

Tristen: OK, I'll check this and pull this off again. (Tristen gets up and prepares the tray for the next test)

Dan: OK, scrape that one out ... and I put five hundred milliliters in.

Tristen: Well, that's just ... (Tristen doesn't seem to think that the amount of water in the tray is worth controlling)

Dan: Squeeze it out, yeah. (referring to the used paper towel)

(Dan seems confident and relaxed now and begins singing, Tristen fills the tray for the next test)

Dan: Rollin', Rollin', Rollin' ... 70.7 grams. So that's how much water the pink ones held. 70.7.

Dan: OK, so the brown is next. We'll stick it with the roll down.

Tristen: With the roll down? Like what do you mean by that?

Dan: Like it curves. Right? You know ... naturally. It's all curving like this so we stick with that down.

Tristen: OK

(Dan places a stack of brown towels in the tray. He seems impatient as he waits for them to wet completely. Tristen pokes at one corner of the towel that is not yet wet)

Dan: What? Did you touch it?

Tristen: Yeah, because it was sticking way up and it wasn't getting wet.

Dan: Oh, well ...

(Dan uses the same method to remove water from the tray. The towel nearly slides out this time as he pours off the water)

Dan: I had a fear that we were going to pour the thing out there.

(Dan places the tray on the scales and grimaces as he manipulates the scale)

Dan: In the conclusion we would like to state that we hate the scales. (smirks at Tristen)

Tristen: We should get one of those electronic ones ... digital ones.

Dan: Oh yeah, you just beep, beep, beep, beep. Our school couldn't afford those. It's like buying a scoreboard.

Dan: OK, five fifty four point eight. (Dan reads the result from the scale and makes a motion toward the recording area)

Tristen: I can do this. (Tristen, who is already sitting, wants to do the recording)

Dan: OK, do you know how ... OK, this is the brown ... OK, two point two times four is eight point eight. OK, I'll get this sorted out. You stuck them in here when we were done. Right?

Tristen: Yeah, after I had squeezed them out. Then I dumped the rest of the water.

Dan: 56.2 ... and the other one was 70.7?

Dan: This is of course assuming that all of these beakers weigh the same, you know. (Dan looks up at us as he says this ... he seems to be showing off a bit because the weight of the various beakers is irrelevant to what they are doing)

(Dan picks up a stack of white towels and stands over the tray)

Dan: Ready?

Tristen: Yeah.

Dan: It took the brown one quite a while. The pink one was just "shooop". (Dan places the stack of white towels in the water).

Tristen: Yeah, but the brown one ... remember it curled up.

Dan: Yeah, it did.

Tristen: We got the two so our results should be fairly precise.

Dan: Hmm ... so are we going to average them out or take the higher one?

Tristen: We should average them because there's probably errors in some of the sheets. You know, since they're mass produced.

(Dan pours the water off the tray and places it on the scale. He notices that the weight is less than it was with the pink towel)

Dan: Looks like the pink one held the most.

Tristen: Hmm ... it's possible.

Dan: I know ... because it's sort of ... so strange.

Tristen: Well, the corrugation. Maybe that's it.

Dan: Or whatever.

Tristen: Probably costs more, that's for sure.

Dan: I don't know. It might cost more. It might be from the Value Village.

Tristen: How would you know?

Dan: I don't know because I've never been in the Value Village, so I wouldn't know.

(Dan looks up at us. Approximately 70-80 minutes has now passed.)

Dan: OK, how much time have we got?

Heidi: Well, until you finish. You decide when you're finished.

Dan: We'll be done once we're done those tests. We're rolling now. OK, five fifty five point eight.

(Dan checks the scale again)

Tristen: Is it wrong?

Dan: Yeah, this thing started swinging again ... point seven ... it's five fifty five point seven.

(Dan cleans the tray while Tristen records the latest results. Their conversation shifts to talk about a fort they are building. Dan finishes preparing the tray for the next test)

Dan: OK, so what's next? We're into the pink again?

Tristen: Yeah, start with the pink.

Dan: That was the top on the list?

Tristen: Uh huh ... 55.5 ... that's how much it held. So it actually ...

Dan: No, the pink held 70.7.

Tristen: The brown you mean ... no ... no ... the white held 55.5.

Dan: Oh , OK.

Tristen: It held the least.

Dan: I thought you were talking about the pink from the last time.

Tristen: No, the white held the least.

Dan: For some stupid reason this one holds the most.

Tristen: It could be the design.

Dan: Well, you know this stuff (points to the white towel) just might be this industrial-cheapo. That's why it's so big and weighs the most.

Tristen: Yeah, when it's bigger, I'm sure it holds the most.

Dan: Yeah.

(Dan places a new stack of pink towels into the tray of water. It wets almost immediately. As Dan pours the water from the tray he is not as careful and the towel bunches up slightly at one edge of the tray.

Dan: Oh no.

Dan weighs the tray and asks Tristen for the results of the previous test with pink towels)

Dan: What was the last one?

Tristen: The last pink one?

Dan: 570.1?

Tristen: Yeah.

Dan: This one's five ... I don't know what's with this thing. It keeps moving once it stops. I bet its got something to do with that fan. (Dan is somewhat frustrated with the scale)

Tristen: Oh well, everything's ...

Dan: Constant? It's always on so ... 589.9.

Dan: I'm pretty sure that the pink is going to be the one that ...

Dan: Brown?

Tristen: Yup.

Tristen: Where are we going to put the average? On the next sheet?

Dan: I don't know.

Tristen: (Tristen reads from the sheet) You may write or draw the answer to your question.

Dan: OK, diagram.

Dan: Do we need to graph our results?

Heidi&Leo: Your choice

Dan: You're not judging in the science fair are you?

Heidi: No.

(The boys continue to talk about the upcoming science fair as Dan routinely empties the tray and places it on the scales)

Dan: What was that one? That was five eighty ...

Tristen: 580.99. What was this one?

Dan: 580.90. Oh no, this stupid thing is swinging again.

Tristen: Is this pink or is this brown?

Dan: Brown.

Tristen: These one's are way higher. That's strange. Well, it's probably because this stuff is so irregular.

Dan: Yeah. 580.90. The thing wasn't done swaying. (Dan prepares the tray for another test)

Dan: Last one.

(There is more talk about science fair as Dan lays a stack of white towels into the tray of water)

Dan: So we should probably decide whether ... see I don't know if we should go with an average or we should go with the higher one. That's what I was thinking about our science project too. Too late to change that right. But if we should have taken a higher one because there was such a huge range in that one ... between three hundred and eight hundred pounds

Tristen: The thing is though that the only reason we took an average is because there is absolutely no way to judge ...

Dan: Well, I mean obviously the one that holds more is the one that's more ... oh, sorry we're off track here.

Tristen: No. It's just one type of wood. Like every piece of wood.

Dan: Yeah but they were all the same. Everything was the same about them. Only the one ... obviously the one that had less was somehow flawed.

Tristen: Yeah, but the wood would probably be damaged.

Dan: Well, then we shouldn't have counted it. Right?

Tristen: Right, but every piece of wood is going to have certain flaws in it.

(The ongoing conversation about science fair continues as Dan pours off the water and places the tray on the scale. He reads the weight aloud.)

Dan: Five hundred and seventy point four.

Tristen: These ones are way higher. You know what Dan. We don't even have to necessarily take the average. We can show both of them.

Dan: On a bar graph? With two things, you know? (Dan begins cleaning up as Tristen works on calculations)

Tristen: Because I think here, even still ... Yeah, The only difference here is that the brown one is stronger than the pink.

Dan: In one of them but it's the other way around in the another?

Tristen: Yeah, by a lot. But the white is still the weakest by a lot.

Dan: In both of them?

Tristen: In both of them. So we can probably conclude that the ... One problem is the pink and the brown. Once, the pink is way stronger than the brown and the other time the pink and the brown holds the same amount.

Dan: Take the average I guess. That's the best way to do that.

Tristen: So I'll average these out and put them on the side [of the bar graph].

Dan: Yeah.

Tristen: OK, the pink is the strongest on the average.

Dan: OK, do you want to put that onto a bar graph ... sort of a cheap one. Here (tosses Tristen a ruler) ... and actually, use the pencil (tosses the pencil to Tristen).

(Dan continues cleaning up while Tristen prepares the graph and they discuss the choice of scale for the graph. When Dan is finished he sits down next to Tristen and notices a statement on one of the sheets of paper asking for a written record of the results.)

Dan: Oh, whoops. We didn't read the one thing that says make a clear record of the results so that someone else can understand what you have found out. Oh well, we did here (points to the graph). Yeah, this is our workout piece of paper. All right I'll specify what this is (writes on sheet of paper).

Dan: We need to make brand names for these things ... Pink Flamingo.

Tristen: These are actually ... these two are fairly close, the brown and the white. But the pink is certainly ... it beats them completely.

Dan: OK, let me see. I just want to re-label these so that they're more clear.

(short discussion about naming the experiment in order to write a title above their bar graph)

Dan: You know what we forgot to do?

Tristen: What?

Dan: Divide by four.

Tristen: No. It doesn't matter as long as they're the same.

Dan: Oh yeah, as long as they're the same.

Tristen: Right?

Dan: I think we should have divided by four there.

Tristen: Yeah, well we could.

Dan: Well, otherwise this is the number that we get here ...

Tristen: We'll do it on the back of the table or write-up another graph.

Dan: OK. (Tristen uses calculator and Dan writes down results in order to divide by four)

Dan: Our prediction was completely backwards.

Tristen: Yeah, it was. Strange. We thought they would go the other way. Actually, they're still fairly close once you take it down to one sheet. (Dan finishes the new graph)

Dan: We should do this for science fair next year (laughs).

Heidi: OK, are you guys done?

Dan: Yup.

Heidi: All right So, can you announce your conclusions?

Dan: Oh, OK. Well we had originally predicted that the white paper would hold the most because it was the heaviest once we had all cut them all down to the same size and that then the brown and then the pink would hold the least. But actually we found that the pink held the most, the brown medium, and the white the least once we averaged out our two tests and then divided by four to find out what the actual amount of water held in each sheet was.

Tristen: and the results were pretty close.

Dan: Yeah, the range is about 19 grams to about 15.7 grams ... is the range from the pink to the white ... that's grams per sheet. If we knew exactly what the temperature of the water was we could find out how many milliliters that was but we weren't trying to find out exactly how much. Just which one held the most and we found out that the pink did. We think maybe we had the right idea when thinking of the weight of the paper had something to do with it but we just sort of interpreted it wrong thinking that the heavier one would hold the most but maybe the lighter one does or maybe this (rips off a small piece of pink towel) ... it's got a pattern in it ... I don't know if you can see it or not but it's got these little bumps in it.

Tristen: This (pink towel) could also have more airspace and stuff.

Dan: Yeah, there could be more room in these. We have to do more testing and stuff.

Heidi&Leo: Thank-you. That was terrific.

Initial Interpretive Feedback Account to the Teacher (Solar House Project)

To: Bridget (Ms. B.)
From: Heidi Kass and Leo MacDonald
Date: February 22, 1994.

This account is meant to convey to you some of our initial impressions about your science class and the way we have observed your students interacting with you and each other. We appreciate the opportunity to become aquatinted with your class prior to initiating a more formal research study for several reasons:

(a) such unstructured non-participant observation allows us to develop a baseline description of the context and setting. This will be very important in our interpretation of what we see and hear when our focus shifts to a more intensive scrutiny of how your students develop understanding in the course of doing science activities.

(b) it permits us to get a sense of how you function in the teaching interaction so that we can develop our research plans in ways that are compatible with your teaching style. This will save time in our communication with each other toward the planning of specific sessions.

(c) it will allow us to develop and refine the logistics of our data gathering activities (including video and audio-taping) so that we can get rich and authentic data in a way that is not unduly disruptive to your normal way of operating your classroom.

(d) it allows the students and you to become accustomed to our presence in your classroom so that everyone will feel comfortable interacting with us.

At this time we would like to share with you some of our impressions based on the four informal visits we have made to your class so far. We would appreciate your reaction and feedback to our impressions from the standpoint of their accuracy, authenticity, completeness, etc. We see this dialogue with you as the first in a series of important conversations about the ways your students develop understanding in science. Please feel free to comment on any aspect of our impressions. Our experience so far has been that the two of us don't necessarily focus on the same things in the same ways and it seems sensible to check things out with the person who is, after all, running the show. No doubt we have missed some aspects of your class and could well do again. Please tell us if you think we've missed something or misinterpreted our observations in any way. Your interpretations of our interpretations are an important validity check of the outcomes of our work.

We plan to prepare a short interpretive account for your reaction every four or five visits. Once you've had a chance to read and think about this account we'd like to talk to you about it.

Your teaching style seems to be best described as an "extended conversation." This conversation seems to continue from one class period to another and involves you with the class at various levels. You use conversations among students as a way of helping them to learn and come to understand science. You seem to value group sharing of ideas, hypotheses, theories, experiences, etc. You often ask the groups to tabulate their observed or measured data, draw graphs, and then to talk about it among themselves. Do you think the students see their interaction with you and each other as an extended conversation?

How do you think the conversations students have with each other relate to the conversations they have with you? For instance, some students seemed to be mostly trying to develop their conceptual understanding in interactions with you while others tended to focus their questions on what you wanted them to do. How does this manifest itself in student-student interactions? Do they focus on accomplishing the task or do their conversations with each other help them to develop a deeper understanding?

Your choice of words when you talk with students strikes us as adult and collegial where ever possible. Would it be accurate to describe your style as invitational rather than directive? Your use of unfinished phrases like "so this would suggest..."or "so your idea is ..." or "the evidence we have for this is..." suggests you have a lot of confidence in your students. Is this true?

You like to give positive verbal feedback to students which indicates that you value their approaches to the tasks and accept a range of student responses from them. We interpret this as an attempt to encourage students to think and act freely without feeling constrained to find "a" correct answer. How do you think your students value this aspect of their learning (process of arriving at an answer) as opposed to the end-product knowledge they develop? You seem to look for self-directness and individual responsibility in your students. For instance, you encourage students to try things out for themselves or leave them to explore with a microscope (from the back room) if they ask a question that suggests its use. Also the onus seems to be on the students to make sense of their data. How independent do you think your students are or are becoming? Could they conduct a meaningful study where they plan (within reason) the question to be investigated and how to go about it? For instance, do they ever suggest or request the use of "back room" equipment to you to explore something further?

You seem to emphasize connecting ideas (i.e. hypothesis/theory/possible explanations) with evidence inside activities and connecting ideas and evidence across activities. How dependent do you think the students are on making connections through your prompting or modeling? Do you observe students doing it spontaneously or getting better at doing it?

You also make connections to the out-of-class experiences of your students and your own personal experiences. Where do the questions that students ask you originate (i.e. from curriculum activities, from outside experiences)? We really enjoyed your analogies and the students seemed to as well.

The group sharing of ideas and hypothesis seems to be important to your teaching approach. What is it about this group sharing that makes it important to you?

What do your students regard as a satisfying investigation? What do you think works for them when they investigate? Have you noticed any significant differences among individual students in what they consider important to do as they investigate something?

There seem to be many things to talk about in all of this. We look forward to your response.

03/03/94 - More thoughts & questions for our next conversation with Bonnie

You seem to encourage the kids to help each other out in their work? Kids even break from their normal partners to give special help to others. How has this been negotiated? Have you noticed any change in the actions of individuals or the whole class as a result of this?

Selected Excerpts from the First Interview with Bridget

June, 1994.

Heidi: ... What were your impressions when we first came and we said we want to study how students function in self-directed environments?

Bridget: I realized two things, I guess. First of all that I couldn't follow up just on your ideas ...I also realized that I had some control over it because I think at the first I saw it in terms of either/or ... I mean ... either we did what you wanted or we did kind of what I thought the kids needed to do ... So that was my first impression ... just all kinds of questions; "How long it would take?" and "How far out of the curriculum would we have to go in order for you to meet your goals?" ... I couldn't see any way of you meeting your goal of wanting the open-ended investigation and my meeting my goal of having something the kids could succeed at.

Heidi: So how did you come to this decision that a potentially doable thing was to design a one-room house, because this seemed to come up quite suddenly?

Bridget: ... I phoned the consultant for Edmonton Public ... and spoke with him and he said "well why don't you just do a one-room house" and then lo-and-behold I looked in the textbook and that's what they had. ... So that was helpful. He gave me some ideas and then I saw some things falling into place. I saw the "ice-cube keeper" leading to ... well, leading the kids to make some conclusions that would be applicable to the solar house.

Heidi: You indicated that your teaching unfolds, so to speak. When you saw these possibilities and as they unfolded, were there any areas of surprise or unexpectedness or where you saw things going in a certain direction and you felt you had to change your tact or direct things in perhaps a different way from what you had predicted?

Bridget: ... after [the consultant] talked about the one-room solar house I was surprised to see that the very same thing was in the textbook. But ... it was in the textbook in a way that hadn't seemed very ... promising either. So I don't know if it was as much an area of surprise as seeing the potential for us to go with that activity and that it could likely be successful ...

Heidi: When you first introduced the house you had already gone and purchased some fiberglass. Can you tell us a little bit about that?

Bridget: I think that came out of my conversation with [the consultant]. He suggested that I keep it simple, to a one-room house, and we talked about some of the materials that I might use and some of those were the same from the ice-cube saver ... You know, the cotton batting and the sawdust and those kinds of things and he suggested the purchase of polystyrene. ... It was ... not serendipity exactly, but all kinds of things came together, it seemed, in the last few days before I introduced that activity to the class. ... Then seeing it in the textbook ... gave it a kind of legitimacy too. So I was pretty sure it was in the curriculum and the fact that it linked back to the ice-cube saver which I had done before in my class. So I knew something about the materials that would be useful for that and I know in my own learning style, I learn best from doing something but once I've done it there's all kinds of little hooks in my mind that I can hang new experiences on. So I could see how I could use the experience of doing the ice-cube saver, when I did it years ago, to do new things with my class this year.

Leo: ... Were you acting in your standard teacher mode as you were interacting with those kids during this self-directed project? Was there anything different about the kinds of interactions that you had with kids while the project was developing?

Bridget: ... you asked about "was I acting in a standard teacher mode?" I don't think so ... I think I ought to tell you that I really saw my interactions, my teaching of this group, the grade nines and the grade eights ... as a kind of a chance to make my mark ... so my ego really got involved there and I saw the possibility of having, of them having a new and better experience by me structuring all kinds of activities for them.

Bridget: But I think with all my classes ... the way it operated ... was to immerse them in activities and that was a new experience for them and not always helpful to them. Sometimes they needed more structure than they got so I wasn't operating in my standard ... well I was and I wasn't ... I wasn't operating in my standard teacher mode because things were much more open ended with this project on the solar house than I would ever have structured them on my own. It would have been much more aiming for closure. You know, "Ok what have you learned from this" and their discussion soliciting the key ideas that I wanted them to learn and so it was quite a challenge for me and I learned a lot from watching you Leo as you maintained your neutrality.

I mean reading about some of the reflection questions that the kids wrote when they responded to whether it was helpful or not to have you in the classroom. I remember Dan and Tristen writing that they just scrutinized your face for clues that you ... that they were on the right track and I realized as I read that that kids do that. I mean we all do that.

Bridget: Well anyway (laughs). I mean it's hard to be neutral. It's so hard to be neutral and not encourage by your ... you know, your facial ... I learned a lot from watching you Leo about how to be encouraging or open without leading them down certain paths and I think it's inevitable in a way that we do that just because of our unconscious responses to what they are saying.

Bridget: I think there were a couple of points that helped me realize the value of being neutral or less directive. One of the points or one of the conversations that I'll talk about is Laura, Karla and Helen were planning to build their solar house with copper wire wrapped around those tubes ... and I listened to their whole explanation and asked questions and at no time did I discourage them from doing that and that seemed kind of like a turning point for me in my interactions with the kids because I realized ... I mean I would not have encouraged that if my goal had been that they get good results. I wouldn't have encouraged them to pursue that line. I asked them about some other things they could have done but I never said "well I think that's a stupid idea". As it happens, through some interaction either with you or clues I gave them or among themselves they decided not to do that. They went instead to more solar collectors with black paper wrapped around the tubes.

Leo: Did that change the way that they eventually spoke to you and had conversations with you? Were there any new ideas that may have come from those kids as a result of that kind of interaction with you?

Bridget: Yeah. I've got so many ideas here. I don't know if I can get them all out ... Like watching you and listening to the way that you interacted with the kids really helped me change the way that I interacted with them. So I want to make sure that I make that point. I did change from being more directive to being more open-ended ... and in questioning just to what the process was ... I mean being less content and more process ... a couple of things that I realized along the way ... like I read your paper that you delivered in Calgary ... the paper that you wrote about Dan's enthusiasm for watching how the paper towel soaked up water and your own interest in the pattern, the shape that the absorption took, and I realized from your looking in detail at that, that the ideas that I got enthusiastic about around the solar house and tried to encourage other kids to follow up usually fell flat. I don't think ... I didn't have the benefit then of reading what you'd written about Dan and your own ... but I think I realized at some point that my pushing my enthusiasms wasn't leading them to do anything and **at that point I just listened, I spent more time listening and just letting them take the lead** instead of me trying to ... kind of "running down a path ahead of them" and saying "come this way, come this way."

I can't remember what Willie and Ronnie had discovered but it was it was really incredible work for them. I mean it would have been excellent work for any group but they had discovered something and I remember bringing some other kids over there and saying something to Willie like "Let me pick your brain" ... I think it was Helen ... and they taught Helen, or told Helen, the line of inquiry they were doing and that for me marked a turning point in how they ... in the responsibility they took for their project. It seemed like after that ... and also after you had them in your room and gave them some special encouragement that they took some ownership and got a really good house built. So part of what I learned, part of the new ideas that I picked up, part of the process I learned was to let them lead with their ideas and lots of new ideas emerged.

Like I'm thinking about when Bernie and Paul developed this special blind that they had on their window that they made out of an Edmonton Transit Pass case and they covered one side of a piece of cardboard with foil. He was so proud of that idea, you know. That was their own idea.

Bridget: ... Well, none of those ideas came from me. I couldn't have thought of all the ideas that came. It was the kids, kind of possessed their idea, you know, and really got attached to them and wanted to follow through how with how it would work out. I wouldn't think that kind of possession, ownership, involvement with an idea ever would have happened if it had been my idea. It's because it was their idea.

Leo: You had a sense that the students were thinking a little differently as the project got started, as they got a sense of the open-endedness of the project and the sense of the way that you were going to interact with them on the project?

Bridget: I think that's part of it. I think the nature of your interaction with them and my changing interaction was part of it but what you talked about in that paper, about you know, Dan catching-on and kind of seizing some aspect of that experiment. I think that happened with these kids as well. I think they seized upon a part of their experiment that was unique and they ... they either ... believed it would be successful or just having attachment too ... maybe the two went together. They had an attachment to that part of the project, to their idea, and believed it would be successful.

Leo: I'm wondering ... for some students ... how do they ... think about other students ideas. You know, when they look at other students projects. I had a sense ... that some students do pay attention to other students work. Laura would be an example, she spoke in the interviews about how she liked to go and look and see what other people were doing. There were some other students who ... seemed not to think so strongly about other people's ideas.

Bridget: ... One thing I noticed was that if a kid had a chance to see their idea through, to being implemented, they really stayed involved and if they didn't, if it had to be abandoned, they kind of gave up interest.

Leo: Yeah. I kind of noticed ... each person had somewhat different roles in that group of Karla, Laura, and Helen. Karla had the original design for the house and Helen came a couple of days later and Karla was informing Helen of her idea and Laura was with her ... acting as an arbitrator in the center ... trying to mediate the thing because Helen would want to add some ideas of her own and Karla didn't think that those were going to be workable ideas and so they had a conversation about "Well lets do it this way, no lets do it this way. Well lets do it this way. No, lets do it this way" and they eventually came to a consensus about what to do. But I mean that was an interesting dynamic. Do you think that that kind of conversation goes on in more structured science activities?

Bridget: No. I don't think there's room for it. I mean there's one right way to do it in most structured science activities ... and they're so ends oriented, you know, they just want to get the results they're supposed to get and get the mark.

Bridget: I think Dan and Tristen's partnership was an example of ownership. Like I heard Tristen say a few times about this high-tech project that it would never work. And yet he went along with it. I don't think that he ever took ownership of his ability to make a difference. Maybe he doesn't have much ability with Dan to make a difference but I don't think he ever took ownership of it in the same way that Dan did.

Leo: Do you see any carry over ... with their experience in the ice cube (activity) where they built that high tech strategy that bombed, which was a real revelation for them and I think was a revelation for some of the other students when they observed this. Do you see any connections perhaps between the way they were going about the house project that was precipitated by some of their experiences in this other activity?

Bridget: Well, my first inclination is to say I don't think Dan can complain. I mean he did the first ice cube saver with the low pressure area and he got the worst results in the class and then he did it a second time and the only thing that was different was that he didn't try to remove the air. I think maybe he put some insulating material between the ice cube and the little metal box and he got better results that time but still nowhere near the top of the class and when he came up with this high tech solution to the solar house ... My first thought was that he hasn't learned a thing ...

Leo: Why do you think that is? ... I mean for Dan specifically, in other areas of his work.

Bridget: You mean the emphasis on finding the most difficult way to do something?

Leo: Yeah, the most complicated or the most high-tech or whatever he perceives to be the most high-tech approach.

Bridget: There wasn't ... we haven't done any other activity that has such open-endedness.

Leo: I mean I got a small inkling of it in the electricity unit when I was doing the motor and being fairly directive I must admit in giving the students directions on how to do the motor. None the less Dan was intent on, Dan didn't quite finish making his motor because he was trying something more difficult than most of the other kids in putting his together.

Leo: Yes. Lets talk about Paul and Bernie a little bit. Would you say that they were acting in a typical fashion?

Bridget: No. They changed so much during the solar house. Paul had been quite ... I have to think of the right words ... typically Paul's way of being in class would be to fool around most of the class, I mean before this project started, to fool around most of the class and then either to ask special permission to hand something in late and still get full marks for it or do it at the very end. But he never really got hooked on anything ... I don't think ... he never really was enthusiastic about anything in science until we did the ice cube saver and they got really good results.

Bridget: They tried cooling it. They did two of them. The first time they did it they had it sitting in the alcohol I think and the second time they put it sitting on some cotton batting and they came in first or second ... and that was like Wow! ... they had quite a low-tech solution and Dan's bombed ... and I think there was something in there that kind of activated Paul.

Leo: That he was on to something and that he had ideas that were worthwhile?

Bridget: I think so. Well, remember ... I don't know if you were in class that time but I was collecting hypotheses to explain some concept and Paul put forth a hypothesis and then Dan put forth a hypothesis and Jill put forth a hypothesis and we looked at all of the evidence for and against and the only one that was supported by all the evidence was Paul's. And that happened right about the same time as his success with the ice cube saver and I think kind of a light went on, like that's what the mental picture I have is. I think kind of a light went on and Paul went "Hmm, you know maybe I can do this after all and beat Dan." Anyway he did really excellent work, he and Bernie, on the Solar House. Up to that time, they had really done just enough to keep me off their case. And it was at the beginning of term three which was in March that Paul set his goal to get honors with distinction this term, which he did. That means honors in all of his subjects. So it seems like several things happened around the same time and he really changed in his way of being involved in the class. He became more of a participant instead of an observer.

Bridget: I didn't see as much change in Clarence. Like Clarence took the initiative from the very beginning of the year. He worked with Nate and did that reenactment of the Hindenburg. They did, you know, throughout the year they have been putting forward new ideas. "Can we change this?" and "Can we go down this little side road?". So that didn't change much. And so that didn't change much. He went down his own side road of the charcoal. What was different I guess was that he worked by himself instead of the partners that he's used to having. He got the best results in all the class with his solar gain and retention and he got help with his Dad on that.

Leo: Yeah, with the idea with the oil.

Bridget: Yeah.

Heidi: ... We are trying to get a sense of the diversity of how kids function when they have control over what they do. There is the option for some of these kids that the control becomes a case of progressive disengagement. In other words, if you truly give people control then maybe one of the options is that they can decide is that they are really not into this. Can you comment?

Bridget: I think you probably had more contact with her (Erin) than I did. ... She hasn't been an active learner, but she did create a design that she was proud of and she showed me all of the details. I think she used a milk carton, a two liter milk carton, did she? Did she have an angled flap in there as well?

Leo: I remember seeing it after it was finished and it was sealed and I remember you commenting about it as I was looking at it at the same time as she was introducing it to you and there was no way in or out of this house, it was a sealed house, and it had sort of a caulking or a silicon sealing the windows.

Bridget: I think she ... Erin is a girl who writes a lot of poetry. I mean she writes poetry all of the time and I think what appealed to her about doing the project was the aesthetics about it and I think that she liked the look of the design. I think it was secondary to her how well it gained solar energy or retained heat. I think it was a chance to create something that she liked the look of. ... And that [testing her solar house] seemed kind of secondary to her anyway. I don't think it was really the function of the house that was most important. It was the form of it.

... my relationship with them really changed. I think that part of it was to whatever extent that they seemed to blossom during the open-ended project. I don't know that it is cause and effect but the two went hand and hand and I enjoyed teaching them more and more and they seemed to get more on track in science.

Heidi: Would you do something along these lines another year and, if so ... what are your current thoughts about how you would ... What would you go with? What would you change? How would you evaluate?

Bridget: Oh, for sure. For sure I'll do it next year, no question about it and I will use much the same sequence. I'll have the whole class doing activities on heat transfer, of convection, conduction, and radiation leading up to it and then we'll summarize the outcome and then they'll do the ice cube saver ... mostly open-ended and I'll try to have time for them to do a few trials. But the thing that I'll do differently is after they've done the ice cube saver we'll do much more of an analysis, what works and what didn't work, and what if we made it. I think that time was a real crunch there. I seem to recall fitting in the analysis into the last two minutes of class one day (smiles). So I think we will take more time to look at the results. Kind of make a list of what worked, what didn't seem to work, if you had it over to do again what would you do.

Leo: That's interesting. Do you have a sense that some kids plan it and then do it or do some kids do it and then get some ideas out of that? How does it move along for the kids?

Bridget: I don't think that either/or ... I think it's both/and ... I think that ... in no way did they say "Ok first we're going to control this variable and then we did an experiment and saw the results" or "Ok, so we're going to make sure our house has this and now we're going to control this variable". I mean that didn't happen at all and I guess **I realized the futility of trying to structure process, that process doesn't happen in a linear way**. I mean it's just kind of like an army marching through a swamp tackling all things on all fronts at once. A lot of the way that we teach science ... when you try to make it linear it is so counter-intuitive or counter-productive ... counter-something or other.

Heidi: Can you comment just to get a bit of closure here ... What kinds of questions do you think you'd like to think through with respect to the assessment. what is your current view?

Bridget: I don't think I would have the outcome for the ice cube ... I would have the reflection

Heidi: Would you give the kids, from the beginning, the option of repeating?

Bridget: Oh absolutely.

Heidi: Because that was one thing that some of them felt rather strongly about that ... that was being scientific.

Bridget: It is, it is and that for me is a real balancing act to give them as much opportunity to repeat the experiment and still finish the curriculum. And with the solar house I think I would keep the evaluation much the same. I really found it helpful for me personally to read their responses to the reflective questions. Most of the kids responded very thoughtfully and I got a lot of information about good teaching from their responses and insights into the kids too, kind of the process they used. So, I'd keep that. I would keep the outcome. What I did was I used the baseline of 70% if they built their house and then they could go up from 70 to 100 based on the outcome of their house ... and that having a graph to kind of standardize the area. Those are all good ideas and I'm going to continue with them.

Selected Excerpts from the Final Interview with Bridget

June, 1996.

Heidi: One of the areas that we'd like to explore with you Bridget is your thinking now about the kids who were in the Invent a Machine project, as we're calling the second engagement, who were in grade nine this year. Did you teach any of them?

Bridget: No. I wasn't teaching grade nine this year.

Heidi: In and around the school environment, Do you have any thoughts or any impressions on the longer term impacts about he kind of work that you do with these kids in grade eight?

Bridget: The first thing that comes to mine is that yesterday we had our awards ceremony and one of the students who was in my class last year, Frank ... won the award for Science and Tech, which is an option that Mr. T. offers and he spoke about Frank's keenness to make science practical and so I thought that ... was really a continuation of the experience that you provided for the grade eights last year where they had more than just a hands-on experience with that real creative, kind of follow your own hunches and see what develops. So my impressions are pretty scattered because of not teaching the grade nines.

Heidi: Are there any other individuals who come to mind who may have in the hall or somewhere commented to you?

Bridget: A couple of kids early in the year ... well, we have had a very disrupted science program for the grade nines. The teacher who started off the year went on sick leave at Christmas and hasn't been back and so they had a number of different supply teachers. So, in the fall, kids would stop by and say, you know, make the kind of comment, "Oh, I wish you were teaching science, we're not doing any labs." So just that kind of thing, but nothing specific to the Machine Unit. But it wouldn't surprise me if their experience with those machines had created a kind of expectation that they ... and certainly they were aware of the grade nine students Solar House and you know they may have had the expectation that they would be able to do some more hands-on experimentation ... open-ended kinds of activities.

Leo: We met Amy one evening at the Jubilee ... we had a very brief conversation with her and she was saying that she missed having you as her science teacher.

Bridget: Well thanks for passing that on. I've heard that from a few kids. Amy had a great project didn't she?

Leo: Yeah, the fish dumping machine.

Bridget: Yeah, I knew it had to do with animals.

Leo: One of the things that you were commenting on, I am going back to thinking about the interview that we had a long time ago with the three of us. You had told us that you had recently read ... one of our papers that we had delivered in Calgary at the CSSE and you were commenting about some of the things you were noticing about your students. For instance, we used a term "embodied" ... and you described it as a kind of ownership or "taking their own idea" and that was a central theme of the sort of thing you were describing. It had an impact on your teaching and it was something you were noticing about your students. Is that anything has continued in any sense ... over time?

Bridget: Trying to give kids more ownership?

Leo: Or noticing that in any sense. For instance, you talked about listening to students ideas and just hearing so many new things.

Bridget: Instead of having such a definite idea of the right answer.

Leo: Are there any ... things that have transpired since our engagements that would be examples of that?

Bridget: You know, as you ask the question the thought comes to mind, I never thought of it in this light but this year with my grade eights I turned the program around. In the past two years we never had time to do the Environmental Interactions unit and I wanted to make sure this year we had time. So we started off the year with that and spent a day at the Devonian Botanical Gardens and I've had students out at the Devonian Gardens before and had them do really structured sequential activities like ... water quality testing and quadrant sampling, that kind of thing, and I wanted to do something quite different and so I had them do reflection booklets and that was so much more open-ended and they had a chance to go and put their own stamp on I guess ... it was something they could take ownership of. The result were quite incredible. They did them in a form that could be bound into hard copy because we have our own in-house publishing here. I think one kid did it like a detective story, really creative. So I guess, now that I think about it, that's one of the ways that I've developed a more project orientation.

Heidi: Are there any curriculum and teaching insights or recommendations or things for future teacher education or in-service or something quite practical. Is there anything that you can see as recommendations here for university people or conference speakers or in-service people to promote?

Leo: And perhaps you could take two perspectives on that ... something for students and something for teachers as well.

Bridget: From the perspective of a teacher, I didn't do anything as ambitious as either the solar house or the machine project this year. I didn't have anyone in the classroom to help me and I think to undertake projects that involve that much chaos without another adult is ... well, I found it stressful even though there was another adult to help, especially in the building part where the kids need so much assistance.

Heidi: Ok, lets pick up on that a bit now. If one were to promote this type of engagement, what sorts of adults? ... I mean certainly having university people and doctoral students ... is one kind of adult but on a larger scale what would you see are some of the qualities that the adult would need to have?

Bridget: A non-directive approach. I think two things would be necessary. First of all, that the person not have a set of answers in their mind and to keep trying to steer the kids toward that "right way" and the second thing would be to have some construction skills.

Heidi: Do you have any recollections or comments about how you saw your role as being modified by the presence of other adults in the classroom?

Bridget: Well, I think in the same way that my approach was modified by listening to Leo. I think anyone coming in to the classroom would have to have some kind of in-service in terms of how to be a member of the class or a resource person without telling the kids the right answers or their version of the right answers.

Leo: Do you think it's really important that kids are able to talk about their ideas with an adult? For instance with three of us in the classroom at one time, how did it modify your role?

Bridget: Well, it meant that I didn't have to be the one person to ... where everyone kind of took a number and stood in line because that I think would be really frustrating and has been really frustrating with the one project that I did do. I think that if the adult had some sort of experience of ... hobby motors or propellers or some kind of knowledge that ... they could bring out if the kids needed that but without saying "this is the way to do it". Like I was just thinking ... I went to Hobby Master over on Whitemud Crossing to get some supplies for a project I did do and I think that would be an excellent person to have come in. I don't know if he has time but he has that kind of expertise ... "Oh this would work, I see the problem you are having and this is the thing you might try working with". The project that I did do was from the Science Plus. It's the air car.

(Bridget shows us the section from the grade eight Science Plus teachers guide, page 185, that illustrates the Air Car and describes what she did.)

Bridget: So this was a narrower project than kind of "anything goes" like you did in the Machine unit and this was manageable for me, barely manageable. But there were still problems you know, in terms of it not going straight, or there not being enough friction on the wheels or propellers hitting the ground but it was more manageable to restrict the project with some parameters.

Leo: Some people talked about that the ... project takes on a kind of larger structure ... One way to describe it is that they develop a kind of confidence, I suppose, or they develop a kind of sense of how they can do something that requires them to be in charge.

Bridget: Some of the learning ... like I'm thinking about the kids deciding that they needed to put rubber bands on the rims of the petri dish wheels because otherwise they got no traction ... so I mean, they are creating friction but I don't know if they could express that in terms of the concept. They just know they have to do that.

Heidi: That's sort of a kind of common sense knowledge. In fact, that's one of the themes in contemporary approaches to cognition that there is .... formal knowledge that you find in texts and curriculum. But just by being on this planet we acquire a sort of common sense knowledge and that's also a legitimate kind of knowing.

Bridget: The girls are kind of handicapped in some of that common sense knowledge because they don't have the hands-on experiences.

Heidi: A lot of them don't, so do you see some potential here possibly.

Bridget: I think the girls benefited the most from this project, by far. I mean the boys had no trouble, many of them brought things they had built at home. But it was the girls that gained the confidence that they could do this and who were most excited about modifying their car to carry their egg or to go the length of the hallway.

Interview with Bernie and Paul

April 29, 1994.

Leo: ... All I want to do is just talk to you guys about what you did in the project ... of building your solar ... house and maybe I'll learn something about how you did it.

Paul: Do you want to know how we built it?

Leo: Yeah, maybe you could just talk to me about what you did.

Bernie: Ok, like you want to know what was in the house and everything?

Leo: Yeah, you can tell me about the house and tell me about how the project developed, how it got started. Maybe go back to ... wherever you think the beginning is and start from there.

Paul: Ms. B. just gave us our assignment to do. Before we made our Ice-cube box and when we were done with that we kept the box and made our house out of it too because it was styrofoam and it was a good size to heat up.

Bernie: We didn't use the same box though.

Paul: Oh yeah, then we changed

Bernie: ... We were going to use the same box, right?

Leo: As the Ice-cube?

Bernie: Yeah ... and then when we cut a hole into to put the window in ... we kept on trying to cut the glass to the shape of the window , but every time we tried to cut, the glass would break. So then, remember that day you saw us in the hallway and told us that you might bring in a glass cutter the next day, we just went home and that day Paul found a new box at his house and then he sealed the hockey card cover cut a hole out, sealed the hockey card thing.

Paul: So then the hockey card cover, you can put cards in it ... we just put tin-foil around a card and then stuck it in.

Leo: Was that just lucky that you found that box?

Paul: ... I wasn't exactly thinking, I was just looking downstairs ... I was just looking for sort of a small piece of window or something and I just found a box and I just found the cover there and so ...

Leo: Right, OK ... and then what?

Bernie: OK ... then we put insulation all around the house ... inside the box ... and then we had this little ledge ... in the box ... and we put a little beaker of water there ... and this black ... construction paper wrapped around it ... taped on it ... so we put water in there and then we started the house. The water was right in front of the window and the thermometer was right up beside the water. That was one of our mistakes, I think, because we should have put the thermometer in the water because that's what a lot of other groups did and they had good results.

Paul: Because I think ... it was just that the light that was heating up the thermometer ... it wasn't ... it didn't exactly have that much heat in it ... so that whatever it gained it lost right away.

Bernie: Yeah.

Leo: ... Did you guys make any decisions as you went along through the project?

Paul: Yeah, like "how we're going to insulate it?" and "how we're going to heat it up?", and "how much space we're going to heat up?" too. Those were the three main questions.

Leo: ... What do you mean by that, "how much of the house you're going to heat up"?

Paul: How much area of the house, of the inside we needed.

Leo: Oh, Ok. ... Tell me about ... what you were thinking about when you were at the beginning of the project ...?

Bernie: Like what out first ideas were?

Leo: Yeah ... did you understand what the project was about right from the very beginning?

Bernie: Yeah, we understood. Our first ideas were like just to have a window and have water already boiling in there, but she said we have to use room temperature water. We were going to have water already boiling in there and then just put insulation all around and then close the window after. That was our first idea.

Paul: and some sort of rocks ... (???)

Leo: ... Are you used to doing this sort of project ... is this a common kind of project that you do?

Paul: We just started "doing" this year.

Leo: ... How would you say that this is a different project?

Bernie: Well it involves building something, you know with materials and then evaluating your results after ... trying to get the best results you can.

Leo: And is that different then ... stuff you've done before?

Paul: Well, sort of the same except we didn't actually build anything.

Bernie: Like one year we used to do experiments, before in grade eight. So you didn't get marked on how good your experiment was ... you'd hand in the assignment and the ... focus questions and whatever. This one you get evaluated on.

Leo: ... Does that change anything about how you did the project?

Bernie: Yeah, I think it makes us work harder.

Paul: It makes you think more.

Bernie: Think more, because you want to get a good mark.

Leo: ... So would you guys consider yourselves to have been working hard while you were ... working on this project?

Bernie: Yeah.

Paul: We put a lot of effort in it.

Leo: Yeah, I thought you did too. I mean, you ... seemed to be working pretty well in the classroom. You did some work apparently, outside of the classroom as well didn't you?

Paul: We were thinking about how to get some materials outside the class too.

Leo: ... Tell me more about what you were doing .... so you were insulating the house ...

Bernie: ... The fiberglass.

Leo: Right, how did those sort of decisions get made to do that sort of thing?

Paul: Just from reading the science book it tells which kind of materials have a high insulation to keep the heat in.

Bernie: Yeah

Leo: All right, and so the science book was one source of ideas that you used?

Paul: Yeah, and Ms. B. would always tell us too.

Bernie: Yeah, she told us some stuff to do

Bernie: Like from knowledge, you know that insulation is used in houses too.

Leo: Yeah, you got that right.

Bernie: ... and it works good.

Leo: ... Did you guys basically agree with each other exactly what you were going to be doing?

Bernie: Well, we had one disagreement. We were going to ... wanted to get the outside of the house black and Paul wanted the inside of the house to be black ... and we ended up putting nothing black (chuckles and smiles).

Paul: It was just actually the beaker that we had because it was the only thing that we were heating up in our whole house.

Bernie: Yeah, so we just thought that we'd put just the beaker black.

Leo: OK, instead of the inside or the outside of the house to be black?

Bernie & Paul: Yeah.

Leo: Does that affect the way your projects go? ... Do you guys usually always agree or do you usually have some disagreements?

Bernie: Well, on the Ice-cube house we disagreed the first time and then we did really bad because we didn't listen to my idea and we had a chance to redo it and we came in first place because he listened to my idea. (Paul gives a nervous laugh)

Leo: When you redid ... you modified your design?

Bernie: Yeah, because he had a box there and I didn't have a box and I was working with him. So I had to listen to his idea because it was his box. I can't just ... I didn't have any box to try my idea in.

Leo: If you were to do anything differently what would you change if you could change?

Bernie: The solar house?

Bernie & Paul: Yeah, we would have put the thermometer in the water.

Paul: And maybe we wouldn't need water. You could put sand or something else ...

Bernie: Or oil, yeah.

Paul: Yeah, oil because sand didn't and with oil in it, it really, really heated up.

Leo: So how would you go about doing that? ... How could that have happened, that you could've used oil or you could have used sand?

Paul: Just tried it out or something I guess, for each experiment.

Leo: Well ... I mean when did you find out that the ... water would have been a good place to put the thermometer?

Bernie: Well ...

Paul: After we did our experiment ... because I was thinking about after "how come we lost so much heat?" Because it was like fully insulated and all.

Bernie: And then we also ... felt the water after and it seemed pretty warm.

Paul: It was **kinda** cool.

Bernie: Lukewarm, it would have been hotter than the rest of the house.

Leo: Right. So why didn't you decide to try the thermometer at that point inside the water?

Bernie: Well, we just thought that putting it beside the water would get the heat from the water.

Leo: OK ... but could you have ... repeated the thing and tried it again with the thermometer inside the water?

Paul: We could. We could have done that.

Bernie: Yeah, and we could have also ... I would have wanted to put the outside black.

Leo: To see if that would have helped?

Bernie: Yeah. I think that would help.

Leo: ... Did you guys discuss that you would have liked to have done?

Bernie: Yeah, I just told him that while it was on. I said that we should have put the outside black but it was already too late because the light was already shining on the house. He thought it wouldn't have mattered because the styrofoam, no heat would get through the styrofoam. But I thought it would just ... make it a little warmer even if a little heat gets in that's better than almost no heat getting in.

Paul: See if you put it inside, then it heats up the inside of the house. So it doesn't exactly go through. The heat doesn't leave through the house.

Bernie: I thought tin-foil inside and black outside would be better because after all the heats in and we close the window, if you put tin-foil all around the walls it would reflect all the heat, keep it in the house ... where the thermometer was.

Leo: Right. Interesting ... that's an interesting idea. I'm interested about science ... how would you describe this if you were to tell somebody what you were doing in your class while you were doing this project? What would you tell them?

Bernie: Well, we'd have to build a house, a solar house ... the teacher would provide us with some materials, we could get some from home too and the object was to shine a light on it for 30 minutes and try to take as much heat after for 5 hours or however long it was, 10 hours. I don't know.

Leo: Ok ... sure. What if that person you were telling that to said "but you're in science class, where's the science that you are doing?".

Paul: Radiation.

Bernie: Our chapter right now is about heat. We're learning about heat and how to keep heat in and how to keep heat out.

Paul: And we're using, we're learning about radiation and radiant energy.

Bernie: Conduction ...

Bernie & Paul: And conduction and convection

Leo: How would you be learning about those things?

Paul: I guess by actually doing the experiment, see how it works.

Bernie: You know like testing out what materials worked good to let in radiation.

Leo: ... Do you guys do any things like this outside of your science class?

Bernie: No.

Paul: We're not exactly into ... going out and just making, doing experiments.

Bernie: No, not really.

Paul: Not unless it's got actually to do something, like for homework.

Leo: Do you build anything at home or do you have any hobbies?

Paul: Not in relation to science

Bernie: No, not really.

Leo: What sorts of things ... would you like to do more ... in your science?

Bernie: Oh, yeah. I like these types of projects.

Paul: You know like actually building something.

Leo: Why?

Paul: Well, it's just so simple ... like taking chemicals and mixing them together ... here you got to actually **make it** and see how well you can build your own scientific thing.

Leo: What makes it scientific?

(Burst of chuckles and exasperated laughter from both)

Paul: I don't know.

Bernie: Say something this time.

Paul: Applying knowledge to it, like in science class.

Leo: What do you think are some of the ... parts of these kinds of projects ... that you think help you?

Bernie: Well, building the actual project ... testing, seeing your results and comparing them with others. Seeing how good you did and what works. Like seeing what some of your classmates did really good, seeing what they used ... and then the analysis I think helps too because we have to ... know what we're doing and not just build anything.

Leo: What do you mean "the analysis"?

Bernie: She made us hand in an analysis. Like ... in a cutoff chart or whatever.

Paul: Cutaway diagram ... like how the house worked, why did it work.

Bernie: Yeah like ... you can't just build a house and then you don't even know how it works or why it worked or why it didn't work. So that's what the analysis is, to ... ask us why we think it worked or didn't work ...

Leo: ... Maybe you could tell me a little bit about that part of it, the analysis. Tell me what you did there.

Paul: Well, we just did a write-up ... about why the house worked, how it worked, what happened, and how you lose heat, how you gain heat, how you prevent heat from getting lost.

Leo: ... Did you both work on that together?

Bernie: Yes.

Leo: In class here or at home?

Bernie: We just ... got some ideas in class.

Paul: Yeah, like we did the ideas in class and I wrote it up at home.

Leo: Did you have a pretty good idea about what to do for that right from the beginning?

Bernie: No. Not from the beginning ... well, I guess we thought we knew what went wrong ... I think it was something wrong that the thermometer wasn't in the water, that's one of the things and the outside wasn't black.

Leo: Why do you think, why would you say that something went wrong?

Paul: Because just the way everyone else's was keeping heat.

Bernie: Our heat was ...

Paul: 23 degrees.

Bernie: Ok, Our house started at 25 ... went up to about ... 45, then it went back down to 23 at the end.

Leo: What did that tell you? How did you analyze that?

Bernie: Ok, like we had a good solar gain but it all got lost back so I think that when the light was shining everything was good but then, after, it started to lose heat ... I think one thing was we should have had the inside tin-foil and I would have also had black ... maybe it would've mattered ... maybe that would have "highered" the temperature a couple of degrees ... the solar gain ... then also to put the thermometer in the water or whatever. We just changed.

Paul: We could have changed something else, instead of water.

Leo: Now ... I remember you showed me, Bernie, you were showing me ... a little cover for the front of the house?

Bernie & Paul: Yeah

Leo: But that didn't work very well?

Bernie: The copy cover?

Leo: Yeah.

Paul: The sport card that was wrapped in tin-foil. It was ... just to reflect the heat or to keep the heat in.

Bernie: I think that helps but I think that we should have had all the inside of the house tin-foil ... because the window was tin-foil ... so no heat was escaping through it. Well, some was but like less than it would be if the window was just open. So I thought we should have had the rest of the inside of the house tin-foil to keep all the heat inside.

Leo: Now one of the things you said that you liked about these kind of projects was the chance to look at what other people did.

Bernie: Yeah.

Leo: What sorts of things can you tell me about that?

Bernie: Well, if your house worked or didn't work you can ... check with say your partner, your friend and see if his worked and you can learn.

Paul: Yeah, see why it worked.

Bernie: Yeah, like why it worked and ...

Paul: What was different about his as compared to yours.

Leo: Can you give me an example?

Bernie: Of someone, like a person in our class?

Leo: Yeah.

Bernie: Ok, Tristen told me when we were setting up our house that we should have had the outside of the house black, and then every other person that did a house, in every grade, had the outside of the house black. Every single person had the outside of the house black. Then when I looked at Clarence's, he had the highest solar gain. His went up to 79 degrees ... and he had tin-foil on the inside of his house and then he had oil too ... That's where I got those ideas. But I thought of the tin-foil from the beginning and the black ... like ... seeing other people with black on the outside and tin-foil on the inside that reassured me that ... maybe I was right and he was wrong.

Leo: If you were to continue the project ... say from today or from ... sometime last week ... after you'd finished testing your house, what would you do?

Paul: Try painting the outside black.

Leo: So you'd incorporate some of these changes into your house?

Bernie: Yeah, definitely.

Leo: Now ... what about the length of time it takes? How much time do you guys like to have ... to do work in science?

Bernie: Something like this?

Paul: About a week to get everything set and made.

Bernie: Yeah, about a week, week and a half, around then.

Leo: About a week?

Paul: Week, week and a half so we can finish all the questions up that she gives us after too.

Leo: Ok.

Bernie: A week and a half just to build it I think ... because you don't want to rush into it, you want to take your time.

Leo: What do you mean by that, when you say you want to take your time?

Bernie: Well, like if you take your time you have more time to think about the decisions you're making in the building. You just don't do it, the decision, you like think about "Well will this work?", then you can ... check in your science book about some ideas or ask the teacher ... her opinion, what she thinks and then maybe you can change your idea.

Paul: Yeah, see what she thinks about how, if you're using the right materials or whatever.

Leo: So is that pretty much what you did on this project, with your solar house?

Bernie: Yeah, we asked some questions.

Paul: I got opinions from everybody in the class.

Bernie: ... We had enough time to do it.

Leo: Yeah, I remember in one sequence Dan was saying to you that he wasn't going to build a window in his house and you guys were saying "Well, we think you need a window in your house".

Paul: Yeah, so we were actually comparing and giving each other our ideas, how to make the house work.

Leo: Ok, well that's pretty good guys. I mean I'm learning something here. I'm interested in how people learn, not just Jr. High students but Sr. High students and College students, all students including myself and so I'm interested about what sorts of things work when people are learning. What would you tell me if you had to summarize it into something? What sorts of things work when you're learning?

Bernie: In experiments?

Leo: Uh huh.

Paul: And explanation, how to do certain things.

Leo: Hmm.

Bernie: Understanding your experiment, not just like doing it.

Leo: Understanding it, if you were to describe that for me, what is the difference between doing your experiment and understanding your experiment?

Bernie: Ok, let's say the ice-cube house right ... you just know that insulation works because it's in your house, you don't know ... why. Yeah. Ok, the ice-cube let's say. You got styrofoam, you've got insulation in it to keep all the heat out, right. Let's just say that it works really good but you don't know why it worked, you just like kind of "fluked". So you don't really know why it works. That's what Dan thought about our project because it worked so good and his, he put so much thought in, you saw his, right? Big pink thing and his didn't work as well as ours. So he just thought that ours was a fluke. But we knew what we were doing.

Paul: We actually understood it.

Leo: So that means that you sort of have an idea of what will happen beforehand?

Bernie: Yeah, that's what we mean. Understanding why it worked.

Leo: And what happened?

Bernie: Yeah.

Leo: Ok, now that's interesting for me. Do you have a feeling when you're learning or when you're understanding something as opposed to when you're not understanding something?

Bernie: Yeah.

Paul: Well, we do checkpoints now. You have to answer questions and then if you were listening and understood you'd get all the questions. If you didn't understand at all you'd guess on every one

Leo: What's it like to be just doing something as opposed to be doing something and understanding it too, at the same time?

Bernie: Well, if you just do something, I don't think you're really learning anything about what you do because you don't know why everything happened. Let's say the ice-cube house and it didn't work, you wouldn't know why it didn't work because you didn't learn anything and then if you were to do the experiment again you wouldn't know what to change because you didn't know what didn't work and what worked. But if you know what you did and if you were to do it again you can make the proper changes.

Leo: Have you done anything in your science where you do something again?

Bernie: Oh yeah.

Paul: Ice-cube box, we did the ice-cube box again.

Bernie: Well most of the experiments that we, like we've never really done anything like this before these two things. So mostly just these.

Leo: Ok, one last question and I'll let you go. Do you guys follow a method when you're working?

Paul: Just follow the book and read instructions I guess.

Bernie: You mean follow a method when we're ...

Leo: I'm not talking about method. I'm just talking about any method that you guys use ... when you're doing ... Were there any similarities in what you did in this ice-cube project to the solar house? To any other projects you've worked on?

Bernie: Like a pattern?

Leo: Yeah.

Paul: Planning out what you're going to use and ...

Bernie: Ok, well we plan it out first and then discuss everything that we don't agree on and then if we still can't find a solution of which one to pick I guess then we flip a coin or something like that.

Paul: Or go ask an opinion.

Bernie: Yeah, ask a teacher's opinion, ask someone's opinion if we can't get to agree on something and then we start building. I guess that's it until we're done and then we do our analysis.

Selected Excerpts from the Interview with Tim, Mark, and Keith

December, 1994.

Leo: I like you to compare your thinking during this project with your thinking in your other science activities.

Keith: I think I was a little more outlandish with this one ... like almost all the parts are used and are still being used ... it has a ... they have a different look ... other than that scientific sort of look ... if you will ... from like science parts and stuff like that from science lab in here ... there's not very much that can look very serious about this thing ... I mean when I think about it this is like a pop bottle for the outside of the car ... that's pretty weird ... but it works.

Leo: Can you tell me a little bit more about what you mean by a scientific look?

Keith: Well it doesn't look that normal ... it isn't normal for something like this to be used in a science project.

Tim: you did.

Keith: Well ... that's why I said not normal.

Tim: Are you not normal? ... I mean a science project can be anything ... that's part of science ... you're creating new things

Keith: Thank-you I know that.

Mark: ... Well ... the problem we had with this was getting it to go ... so I just thought of something that we could [do to] reduce the weight by over half (points to Keith' car) ... just sort of Keith's idea ... put a pop bottle and have some wheels on it ... and just put this [rocket engine] through the middle ... make a hole and have it go much faster ... you could just put the weights inside and it would still be lighter than this [holds up their CONSTRUCTS car].

Tim: But the only different ... the only thing I'd like to do now is ... if I made out an extension of how to puncture the CO_2 cartridge with a very small hole ... but equally ... you can just have a way of tying a tubular coil here ... and you can somehow just push them together and they'll pull something like this (gestures with his hands) ... and that will poke a hole in it and then it will shoot (gestures with hands some more).

Leo: ... Will you be able to do well on that [analysis] do you think?

Tim: Yes.

Mark: Because we understand our project.

Keith: Anybody could do really well on that if they know what their machine does and what types of problems they. They can do well if they know their machine well enough.

Leo: Tell me about this "knowing your machine" or "understanding your machine". What is it that was special about your thinking and your way of thinking in this project that allows you to know your machine and maybe someone else not to know their machine quite so well?

Keith: Well I knew what my project was going to be from the start ... I had sort of a vision ... shall we say ... of a car ... not going too fast or anything ... but just moving ... just enough to keep a five hundred gram mass going ... and if you have an idea right from the beginning it sort of develops as you go along and it gets embedded in your memory ... like you know it off by heart from there.

Leo: (turns to Tim & Mark) OK ... what is it that allows you guys to understand your project and will allow you guys to think that you can do pretty well on this write-up?

Mark: We worked hard on it.

Tim: We worked really hard in class ... like we never fooled around ... I have this memorized now ... I could make a drawing of this after not seeing it for a long time and I could get every joint or piece of plastic on this in the right place .. I have such a good feeling for it ... because I know it ... and I also have developed knowledge of it ... like how you work with CO_2 cartridges. I know why it didn't go well [in the class presentation]... and I know why it did go well the first time [first test].

Leo: ... Tim ... how about you ... can you compare your thinking and the way you were thinking in this project with the way you think when you're doing other science activities?

Tim: Well ... it's a bit different when you do something like this when you can actually make things. A lot of the other science activities you do ... we have something that we're supposed to do ... ahh ... we have .... we read from the textbook and we have to put .... to see who can dissolve salt or something ... **and here we can do whatever we want** ... and it was ... **so like then I thought differently** ... I didn't think from the book and think of from like a professional scientist's kind of point of view ... I was thinking of ... of what a kid would like ... but also someone that maybe like ... a scientist wouldn't care as much about like those little rocket powered cars ... I was thinking more of people my age, of what people our age would like.

Mark: Well ... when I have a project that I can choose what I'm going to do ... I'm usually ... usually a lot of people don't do what I'm thinking of ... last year I did for my science fair project an experiment with ah ... bean seeds and steroids ... and no one else did that ... in the school ... and there are other projects that were repeated by other people and I'm just doing an extension of that this year ... and I found that no one else had the idea of using a CO_2 cartridge or a rocket launcher or a rocket in a science project with machines.

Leo: So you feel that you have an opportunity to have some originality in a project when you think for yourself that isn't present ... maybe as much ... when you're doing something from a textbook or somebody else is giving you directions?

Tim & Mark: Yes.

Leo: I was interested Tim, in your comments just now that you were thinking more about what someone your age would like to do and you were saying that was a little different from your other normal science activities ... in the textbook for instance where it's stuff that a scientist would want you to do. Can you tell me a bit more about that?

Tim: Well, it's like when we do science normally we have to do ... we have to learn about ... different aspects of the science world ... but were actually not inventing anything ... whereas here ... well this didn't actually turn out all that well ... but like I made a car ... and there's tons of little kids ... or people of my age that would like a car... I know ... our IA teacher I found out has made ones that are much different ... they're made out of wood and ... they got like close to a hundred kilometers an hour ... Yes ... real fast with CO_2 cartridges.

Leo: Perhaps you could tell me a little about how you guys see yourselves as thinkers ... is there anything special about you Tim?

Tim: Well ... I don't really think I'm really special compared to other people ... but I tend to be kind of creative ... in terms of using different things ... because like the thing I don't like other people doing is like using ... well usually people use LEGO and use a motor with it ... because that's just something a little person ... like anyone could do ... and like right here we use CONSTRUCTS which is something that they don't even make anymore ...

Mark: Unfortunately ...

Tim: Yes ... like Mark collects CONSTRUCTS .... but ... so that's really different ... but also some rockets get very advanced ... I have quite a bit of experience with them ... and there's different ones that can carry eggs ... they can carry eggs and ... insects and they have different compartments and they have different ways ... you can have one rocket go ... it will go up and it will hit the next one so it light up the next one so it keeps on getting extra power ... so I think I'm a bit different that way ... I take a bit of a strategy and using something more powerful than just a normal motor or battery powered car.

Leo: Can you add anything to that Mark?

Mark: Well ... the problem we had with this was getting it to go ... so I just thought of something that we could reduce the weight by over half ... just sort of Keith's idea ... put a pop bottle and have some wheels on it ... and just put this through the middle ... make a hole ... and have it go much faster ... you could just put the weights inside and it would still be lighter than this.

Leo: Yes ... it was a nice idea ... I agree ...

Tim: The thing with this I thought ... we ahh ... I wanted something that looked more like a real car ... like LEGO things ... they can like ... so they can turn into anything ... you can turn a car into a robot ... you can turn a car into a frog ... and like with this ... I still hope that we can get ...more of a real construction look to it ... that's with squares and rectangles ... I thought it was more realistic this way ... before we had the inclined plane kind of like a windshield.

Leo: Right ... I remember ... I remember it well ... it was nice ...

Mark: I'd like to do this again ... but without the weights ... just to see if we could have it go straight this time ...

Keith: Why not just take off the top deck here ... like take off most of the unnecessary pieces

Mark: Well that's not the problem here ... because when we tested it in the hallway it didn't go straight ...

Tim: Actually it did ... actually I thought of a way to do this ... you take this thing out ... this part right here ... and you can actually get it in the middle ... like sometime it kind of bulges out ...

Mark: Don't break it ..

Tim: He really likes his constructs

Mark: Well my mom said she didn't even want me to bring it ...

Leo: Really?

Mark: Yes

Leo: Why not?

Mark: They're worth a lot of money.

Leo: Oh really ...

Tim: See it's kind of like that ... and then it's in the middle and it can go straight now ...

Leo: And why is it important for it to be in the middle ... oh ... because it will help it go ...

Keith: It will keep it going straight ...

Tim: Yes ... we couldn't put it in the middle before because of the beams ... they are down in the middle on both sides ... can you see inside there?

Leo: Yes ... yes.

Tim: And the strip inside is forcing this part up ... and if really was a problem, which I really don't think it would be, we could use tape or something just to hold this here ...

Leo: More stability ... ok ...

Tim: Yes.

Leo: Maybe we could compare this a little bit to ...

Keith: Each other's?

Leo: No ... I like you to compare your thinking during this project with your thinking in your other science activities.

Keith: I think I was a little more outlandish with this one ... like almost all the parts are used and are still being used ... it has a ... they have a different look other than that scientific sort of look, if you will, from like science parts and stuff like that from science lab in here ... there's not very much that can look very serious about this thing ... I mean when I think about it this is like a pop bottle for the outside of the car ... that's pretty weird ... but it works ... at least ...

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Tim: You did ...

Keith: Well ... that's why I said not normal ...

Tim: Are you not normal? ... I mean a science project can be anything. That's part of science, you're creating new things.

Keith: Thank-you I know that ...

Leo: OK Keith ... that's great ... I appreciate your comments ... Tim ... how about you ... can you compare your thinking and the way you were thinking in this project with the way you think when you 're doing other science activities.

Tim: Well ... it's a bit different when you do something like this when you can actually make things ... a lot of the other science activities you do ... we have something that we're supposed to do ... ahh ... we have .... we read from the textbook and we have to put .... to see who can dissolve salt or something ... and here we can do whatever we want ... and it was ... so like then I thought differently ... I didn't think from the book and think of from like a professional scientist's kind of point of view ... I was thinking of ... of what a kid would like ... but also someone that maybe like ... a scientist wouldn't care as much about like those little rocket powered cars ... I was thinking more of people my age ... of what people our age would like ...

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Mark: That's because they only weighed a few grams ...

Tim: But ... the only different ... the only thing I'd like to do now is ... if I made out an extension of how to puncture the CO2 cartridge with a very small hole ... but equally ... you can just like ... like have a way of tying a tubular coil here ... and you can like .... somehow just push them together and they'll pull something like this ... and that will poke a hole in it and then it will shoot ... but ... it's just better if you can do something that you would like ... that's definitely something that I am interested in ... something that other people are interested in ... more than ...like ... doing something with salts ... that like ah ... I'm not going to go home ... like hi guys ... my friend calls me up and says "hey, want to go skating on the rink?" .... "ah no I'm going to do an experiment on salts/" ... like it's just something that I'd rather do.

Final interview with Dan

August 16, 1996
University of Alberta

Heidi: Did you do any more projects? Did you do any more building in the Physics 20/30?

Dan: In Physics 20 we did a catapult project where the net mass of your catapult was limited to 900 grams or something and we were launching a scientifically standardized "Hacky Sack" as far as you could propel it. I think my friend Tristen who participated earlier on in this project was my partner for that and we came second I think. But the top people, their Dad was an engineer and they made it out of plastics and fiberglass and the rest was a massively reinforced deal and of course Tristen and I built ours the night before in the garage in my house as is the norm with most of our projects except for the car. That one was well thought out in advance. But ours launched something like 18 meters and the best one launched 23 and then everybody else was down around 6 to 8 meters.

Heidi: OK, so that is interesting. Yes, thinking about those projects that you have done over the years in the building projects, do you still have any of them. Do you still have your car or your Solar House?

Dan: I still have the Solar House and I still have ...

Heidi: Do you!

Dan: Yes, it's in the basement somewhere.

Heidi: Can we stop by and get it?

Dan: Oh, I don't know, I suppose. I think it might be missing one or two of the key parts but I think "in spirit" it's still alive, anyway. And I have the catapult too.

Heidi: Yes, the catapult wasn't really a part of our project, we didn't see it, we didn't know this was happening. We were engaged in some other things. But would you mind? I just thought it would be very interesting ...

Dan: It's taking up space in my basement right now. Absolutely, if you want to swing by and get it.

Heidi: I think Leo could probably put it together again.

Dan: (looks toward Leo) I think it's missing a piece of glassware that we borrowed and had because we had some sort of bellows strapped on to it because we knew there was going to be some pressure changes in the system.

Leo: You wanted to equalize the pressure. I think you wanted to keep the pressure from popping the tube.

Dan: (gestures with his hands) Yes. Because you remember we had, past the condenser inside there, well it wasn't a condenser because nothing would evaporate, it wasn't that hot. But past the heat exchanger coil when the water was on its way back out we had a "T-piece" of glass tubing and our tubes connected on the bottom edges of the "T" and then there would be the vertical portion which had a balloon strapped on to the edge that kept the pressure from changing. But I think the glass tube is gone.

Heidi: Thinking back, what stands out in your mind now that you have finished your high school physics about this sequence of projects that you have participated in over the years.

Dan: Well, I guess the trend I noticed was that just about everything we did related to dynamics or kinematics and then we did some experimentation with electrostatics and magnetism. But there is a real focus in Physics 30 when they changed the course a few years back they put a huge stress on atomic theory things ... But there wasn't a lot of stuff that we could do in class for those. It wasn't a problem for me because I could understand the theory while we were going through these things and I would read in the textbook to get a different perspective, an explanation always, and just to verify everything, and get just a different sense from a different "explainer", a different explanation on whatever we were talking about in class that day or the day before.

Heidi: Could you tell me a little bit about this different perspective or different explainer?

Dan: Well, this was something Mr. G. had explained to us earlier in the year. ... For different people with different learning styles, sometimes something he says is not going to come across as concrete as he might like. And often times then the next step, rather than going back to Mr. G. because he's going to try to explain it to you the same way again just out of force of habit, because that's the way he has been explaining for all those years, would be to either go to one of the other physics teachers in the school or as a sort of first step try the physics textbook, and look in there and see how they would explain it. Because our textbook can be extremely obtuse at times but other times it was really good just to hear sort of with somebody else's voice. And if you hear something twice from the same person then you're going to ignore it ... but if you hear it twice from different people then because there are subtle differences in the way things are materializing in the explanation then you are going to pay better attention and then from the two assemble something hopefully even greater than the sum of the parts.

Heidi: What about yourself as an explainer? Was that a way that you could perhaps look at those building projects that you did? Was there anything that you were explaining to yourself when you were building the solar house or the car or the catapult?

Dan: Well, what all of those projects, sort of, were forcing us to do was take a look at what was going on, why things worked the way they did and if you didn't understand that then you could put something together that kind of worked but it wasn't going to be as satisfyingly functional as if you understood what was going on and tried to harness the forces at work. For the Solar House you had to understand the principle of heat retention in water and insulation. And those are fairly basic concepts but some of the people just were not motivated or didn't see any real incentive to try and understand. But I realized that the only way that we were going to do anything spectacular with the project was to look at the theory and looking at the theory first in what we had learned in the classroom and then trying some things out ourselves to make sure that what we were seeing happening on the chalkboard was the same as what we were seeing in the book. And when we were satisfied that those things were coinciding then we were happy and then that's when we finished the house.

Leo: One of the themes that you and Tristen described as your way of doing ... the Solar House project ... was the idea of taking a risk, of wanting to add something new into the project that perhaps had not been included in what you had been learning class.

Dan: Well that's the magical part of learning, ... when you can take something that somebody has told you and then add something yourself to it so that at the end of the day you're left with way more than you started with and sometimes the only way to get that is to take a chance. Is to vary something, do something differently, step out on a limb, and see if something works and if it doesn't, you've learned something and if it does, you've learned something ... equally valuable, maybe more valuable, maybe less valuable. But ... then what that does, is that causes you to ask more questions, and that's what the game is all about.

Leo: ... You and Tristen have continued to work together for quite some time now. Have you noticed any progression in the way that the two of you think and do things when you work together on building projects?

Dan: Well, I've found that I still like to take risks and try things new but I'm a little more conservative now in the process of just trying things. Instead of just whacking things together and trying them, I'm being a little more careful now with keeping track of what I'm doing and keeping track of the subtle variations and results that we're finding when we're fooling around with new things that work or don't work. And that stretches beyond just science, that goes into everything I do, I guess. There's a little more of a process, a little more something concrete behind ... (pause) something methodical now, is what I'm finding, more of a method, more of a restraint. I guess you lose some of the excitement then, but you get more out of it at the end of the day.

Leo: Are you telling me that, in a sense ... you don't really see yourself as playing ... as much as you used to at the beginning of things - before you get into the more serious building of an apparatus and developing a clearer idea of what it is you will do when you work on a project? Do you ... have a better sense of what that is now, from the beginning?

Dan: Well, my perception of the value of knowledge itself has changed. In Junior High when life was one day to the next and it was who is dating whom and what's on TV tonight, then science was fun because despite all of the STS - Society, technology, and whatever, I can't remember.

Leo: Science-technology-society

Dan: Science-technology-society. Despite all of that, the focus on that, we were kind of (shrugs) through science class anyway. We just wanted to have fun fooling around with the concepts and understanding what was going on, but we didn't really see necessarily the value of it. But now, maturing as an individual but also entering society as an adult, I'm starting to see more the value of knowledge itself - scientific, sociological, anything like that. So the process of learning has become a lot more serious for me over the past few years. So it is still playing, it's just that the rewards are more mature, more adult.

Leo: Would you characterize some of these more extended projects as contributing in a positive way towards that new clearer focus that you have about the value of the learning that you are doing now?

Dan: Well, I guess what I'm sort of getting at is that learning was fun and it's still fun but now there's a value to it, not something that you can put a dollar sign in front of and anyone who limits themselves to that is foolish, but a value both to yourself and then potentially to society too. You never know.

Heidi: So it's deeper, in a sense. It's more complex?

Dan: Yes, it's a much more meaningful experience to learn because the gathering of knowledge is what makes you stronger. I pity the ignorant, I guess. Just because learning things ..., I mean especially in physics, learning about atomic theory and these other things and having it all come together was a fascinating experience for me because I knew ... , and it was unfortunate, so many people had said "No, I'm not going to take Physics 30, I don't need to, I don't want to, I don't need to know about that". You don't need to know about very much to survive in the world, but if you don't want to know then you're missing out.

Leo: So you think that is something that is very alive for you, "the need to know and the desire to know more"?

Dan: To understand the world around. That's what modern man has been trying to do for the last couple of thousand years and we are getting sort of increasingly close to a whole understanding of what is going on and I find that just triumphant.

Heidi: Do you see yourself participating in this understanding, or are you thinking about that?

Dan: Well, that's always in the back of my mind, I can never decide what I want to do. I did one of those career assessment quizzes onetime and I got waste disposal manager. That's not something that I aspire to but that just confused me totally. I just want to continue to enlarge my understanding of what's going on.

Leo: Aside from the specific concept things that you learned in something like the solar house project or the mousetrap car project or this more recent catapult project, ... are there other things that you learn over time by participating in those kinds of projects?

Dan: Well, there was not always, when we were doing those kinds of projects, an emphasis on the scientific method. But you had to apply it somewhat, even subconsciously you had to apply it, in the sense that you had a hypothesis into how something might work and then you tried it out. But later on, like with our catapult, even though it was done the night before, we were left with just trying to figure out what size of "bungie" cords to put on it. So we took it out into the back lane and we let fly with the different "bungie" cords and we were careful to make sure we didn't rip the thing apart and so on, and we kept track of our results and we wanted to find out what one was going to work the best. Because if we put on one that was too big, we were going to break the thing, and if we put on one that was too small then we weren't going to take full advantage of the mechanism.

So there was a method and there was an analysis and there was, through that whole process, ... a scientific approach - a methodical approach to it which some of the other people (who) just whacked it together with duct tape and old hockey sticks the night before didn't have. That's something, you know, a step in the process which became more and more apparently useful as we went through it. Because if we had gone back and we had tried some different things with the solar house before we had just whacked it together, there are a couple of things in retrospect we might have done differently. And it goes that way with every project, ... things that we could have done differently.

And that was one of the things about our learning experiences ... with those projects. ... Afterwards, most of the people just threw their things away. A lot of them are just sitting in the back physics room in the school or in the basement or they're just in a "dumpster". Some people threw theirs on the Calgary Trail and watched a truck run over it. No, that was the Mousetrap Car. They were disappointed with the performance of their car so they threw it onto the major road. (It was a pathetic car actually, I must admit.) But that was one of the things that we did differently. ... We took the mousetrap car apart (and), as we were taking it apart, we were asking ourselves "If we had done this differently ...?" And when we had the catapult, after we were done and we had seen what the other people had done, we were like "Oh yes! That different bit of structural reinforcing there allowed their thing to flex a lot less ..." and so on. We just were able to analyze and wonder about these things. ... I mean we didn't take our project away and then try to refine it. I mean we could have, but we didn't.

But I think it was a major step to be even asking the questions after the fact because that demonstrated to us, and to the teacher, and to some of the other people in the class who we were talking to about the projects, that the experience was more than just putting the thing together and doing the trials and then throwing it away. That asking the questions about what you could have done better, how you would have changed it, (and) how you would have done things differently is another integral part of the learning experience and the importance of that is becoming increasingly apparent to me over the years.

Leo: I am really intrigued about your more recent, in the past year, ... projects that you developed personally on your own. For instance, the CAD (Computer Aided Design) project in which ... you have begun your own business. Has any of the work that has gone before, the project work that has gone before, ... contributed in any way to the kinds of strengths that you have now ...? First of all, tell us about this project, since we don't know what this project is.

Dan: Oh, right. Well, a friend of mine and I took a drafting course together at school. For most people, the drafting course was a "mouser" course, a "mouser' option so they didn't care what was going on but my friend and I were just having a blast and we decided eventually, I can't remember how, to start our own drafting company doing computer mechanical drawing, architectural drafting, 3-D rendering, these kinds of things for people who were willing to pay for it. And mostly it was just something to do, something to refine our skills in those areas.

Leo: That's an interesting project. You would characterize it as a project now, would you? Or how would you characterize it?

Dan: Well, I'm not sure that I would characterize it as a specific project, more of a kind of a mission and it's not a thing designed to make us a whole ton of money because if we charged a whole bunch of money then people could go off and get it done by people who have certificates to prove that they're good at this.

Leo: What I am asking is ... the skills that you bring to this company with your partner ... have they been developed in any way by your experiences in more extended building projects in the past?

Dan: Well, the process of design for me has changed. I used to draw things, when I was sketching, with pen but now it's pencil just because the concept of setting anything in stone early in the process ... that doesn't work for me anymore, that doesn't do anything for me anymore. That's one of the things that the computer has allowed me to do now, moving from the pencil to the sort of ultimate erasable realm, the computer. So I can just "select" areas and "drag" them around. I can say "No, the kitchen is stupid there, I'll just move it over here. It works better there." I can flip things around, I can really have the different dimensions of something at my fingertips right there.

It is a process of, I guess in a sense it is a similar process of varying what I do and then trying some different things with it and running things through the 3-d rendering program to see what they look like because something can look good on paper ... In the old days something would look good on paper and then you'd build it and then you'd look at it and you'd say "No, that's stupid" or you would have to build one of those horrendously complicated cardboard models that take hours and hours and hours to do. But now with the computer we can just punch everything in and do a 3-d rendering of what the place will look like from the outside and we can also render the inside and we can go so far as to put appliances in and so on and get a real, very life-like perception of what it would be, what it would look like if somebody chose to build something based on our designs. But then we can go in there and we can look at it and we can say "No, that doesn't work" and go back and change it again and it's a sort of a never ending process, the same way as everything that we have done before with the projects, the building projects.

Leo: ... During the Solar House project you did quite a bit of writing, not a lot of writing but you did complete a fairly detailed report of the project. One of the things that is interesting is that you are a good writer and so you gave a very good description of the process that you and Tristen followed and that you developed. What role does the writing contribute to your thinking in these kinds of projects?

Dan: Well, it's one more incarnation of the project. Building the actual Solar House itself is sort of the first and most obvious incarnation of what you do. But then this subsequent materialization, one of them was on paper and one of them was, well, the first one afterwards was in my mind, of what I would have done differently and then the paper that we wrote was a refinement and an extension of that again. So that's sort of another element of the never ending process there.

Heidi: Do you remember how you organized that report because we found it very interesting? What you did Dan, in the report that you submitted along with the diagrams, you organized the report in a certain way and what were the headings? Leo, do you remember the headings?

Leo: Yes, the general headings were, you talked about the "outsides", the "insides", and then "testing it".

Dan: Oh right, yes.

Heidi: Yes, we are interested in that organization, in what you might have been thinking about in how you were doing it.

Dan: Well, I guess what we were doing was taking the whole project and breaking it down from the outer level to the most specific. So that's how we progressed from the outsides of the house itself. But also the theory that goes along with that, the passive solar.

Heidi: OK, so what do you mean by the outsides?

Dan: Well, what we were doing there was sort of cutting things in half each time we went and splitting things open and looking at things at a finer and more detailed level each time.

Heidi: See, there it is. (Leo shows diagram from thesis to Dan).

Dan: Yes, well that's a fine looking diagram if I do say so myself.

Heidi: ... You talked something about the outsides and then the insides, and then testing it. So tell us a little bit more about what do you mean by the outsides.

Dan: Well, the outsides is sort of the surface of the experiment and then the insides is a more detailed look at it and then whatever we did after was the sort of ultimate theoretical implications.

Heidi: OK, so this a conceptual moving from the outside?

Dan: Yes. We were breaking things down and getting sort of progressively more detailed and looking closer and closer at what was really going on, going from the outside, sort of what we visually perceived to what is going on.

Leo: One of the things that struck me is that some students seem to treat their work as a kind of a one shot thing and when I ask them to talk about their thinking they don't often talk about the overall process that led into the design of something. They talk about where they ended up, for instance. Your write-up was striking because it seemed to characterize the whole process of building from start to finish. Perhaps it didn't include everything but it seemed to be more process oriented as opposed to just describing "This is what we ended up with". Would you describe that as something you are aware of in your work in general, that you do think about "How we are getting along" in ... developing something? For instance, in the Solar House project?

Dan: Well, nothing is a one shot deal for me. Everything is interconnected, everything relates to everything else. Sometimes you have to look for the significance in a relationship and I think that challenge of having to sometimes look for what's going on is what stimulates me to look for what is going on. But at the same time, for so many people that is what prevents them from looking at it. That's just a part of my personality. I know it's cliché but I question rather than I quit. (That's so bad, I know. It comes from Sesame Street or something.)

Leo: Do you think you will continue to build things? Would you say that you are building something in another sense when you are doing the CAD (Computer Aided Design) work and will you continue to do physical building in the future?

Dan: The physical building is an extension of the real building which is in here (points to head) and that I'll always be doing, I know that. I'll stop when I'm dead. Building things physically is part of the process and building things mentally is the process, period.

Heidi: Well thank you. That is a wonderful place to end.